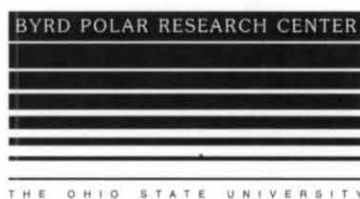


# Workshop to Define Research Priorities for Russian Arctic Land-Shelf Systems



January 10-12, 1995  
Sponsored by National Science Foundation  
Arctic System Science Program



BPRC Miscellaneous Series M-335

BYRD POLAR RESEARCH CENTER  
THE OHIO STATE UNIVERSITY  
COLUMBUS, OHIO 43210-1002

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**WORKSHOP TO DEFINE RESEARCH PRIORITIES  
FOR RUSSIAN ARCTIC LAND-SHELF SYSTEMS**

**(abstracts)**

January 10-12, 1995

Byrd Polar Research Center  
The Ohio State University  
1090 Carmack Road  
Columbus, Ohio 43210

Sponsored by  
National Science Foundation  
Arctic System Science Program

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# **Background and Mission Statement for the "Workshop to Define Research Priorities for Russian Arctic Land-Shelf Systems"**

Byrd Polar Research Center, The Ohio State University

January 10th to 12th, 1995

The recent improved access to the Russian Arctic provides unparalleled opportunities to gain a pan-Arctic understanding of environmental processes and events and relation to global issues. However, there has been little coordination within the North American scientific community and with European colleagues on research priorities in the Russian half hemisphere of the Arctic. With support from the Arctic System Science Program of the U.S. National Science Foundation this workshop was organized to define key scientific questions related to processes and environmental change of the Russian arctic continental shelves and adjacent lowlands.

This workshop will focus on defining interdisciplinary and circumarctic research priorities to elucidate land/shelf interactions from the present through the Cenozoic. Of particular interest is understanding the linkages between processes and events from the watershed to and across the continental shelf. Discussions will focus on defining major oceanographic, terrestrial, and atmospheric processes that presently control and, in the past, altered the distribution of biota, sea-ice, permafrost, glaciers, and river discharge. A unifying theme is how the Arctic contributes and is affected by global change. The ultimate goal is to provide improved boundary conditions for climate models and the needed insight into the role of the Arctic in modulating global climate and human migration.

This will be a "working" workshop, in which ideas and text from participants are needed to generate a community-based science plan for future research on the Russian continental shelf and adjacent lowlands. This science plan will emphasize the continuity between contemporary processes, and past and future environmental changes. It is particularly important that participants bring to attention critical new avenues of research. A potential focus area is the Chukchi and East Siberian Sea and Lowlands because of the unique linkages to the North American Continent. Participants should have text in hand or be prepared to relay prose on specific insights.

A science plan with prioritized scientific issues will result from this workshop as outlined below:  
FOREWARD

## **EXECUTIVE SUMMARY**

### **I INTRODUCTION**

- A. Background
- B. Program Focus

### **II SCIENCE OBJECTIVES**

- A. Flux of Sediment, Water and Ice
- B. Cryosphere Interactions
- C. Biogeochemical Cycling and Ecosystem Dynamics
- D. Human and Biotic Evolution

### **III CROSS CUTTING ISSUES**

### **IV PLAN OF ACTION**

Paleo-studies	Present studies
observations	experimentation
correlations	processes
Integration and synthesis	
Modeling and prediction	
Consequence and impacts	

### **V LINKAGES**

### **VI CONCLUSIONS**

**Composition of Discussion Groups for Russian Land-Shelf Systems Workshop**  
Wednesday January 11, 1995

***Flux of Sediment, Water, and Ice Group***

***Group A***

Stephanie Pfirman, co-chair  
Ray Cranston, co-chair  
Kathy Crane  
John Edmond  
Dieter Futterer  
Larry Hinzman  
Ola Johannsessen  
Andrew Lapenis  
Leonid Polyak  
Leonid Timokhov  
Erc Reimntz

***Group B***

Stephanie Pfirman, co-chair  
Ray Cranston, co-chair  
Peter Clark  
Jackie Grebmeier  
John Hobbie  
Youngsook Huh  
Heide-Marie Kassens  
Lonnie Thompson  
Vladimir Romanovsky  
Mike Waters

***Cryosphere Interactions Group***

***Group A***

Julie Brigham-Grette, co-chair  
Scott Ishman, co-chair  
Valery Astakhov  
Jerry Brown  
Peter Clark  
Valery Gattaulin  
Heide-Marie Kassens  
Gifford Miller  
Vladimir Romanovsky  
John-Inge Svendsen  
Lonnie Thompson

***Group B***

Julie Brigham-Grette, co-chair  
Scott Ishman, co-chair  
Kathy Crane  
Dieter Futterer  
Pat Anderson  
David Lubinski  
Leonid Polyak  
Leonid Serebryanny  
Andrei Sher  
Leonid Timokhov  
Erc Reimntz

***Biogeochemical Cycling and Ecosystem Dynamics Group***

***Group A***

Skip Walker, co-chair  
Walt Oechel, co-chair  
Pat Anderson  
Jonathan Bart  
Wendy Eisner  
Jackie Grebmeier  
John Hobbie  
Youngsook Huh

***Group B***

Skip Walker, co-chair  
Walt Oechel, co-chair  
John Edmond  
Andrew Lapenis  
Mary Edwards  
Larry Hinzman  
Igor Krupnick  
Douglas Siegel-Causey

***Human and Mammalian Evolution, Migration, and Occupation Group***

***Group A***

Bill Fitzhugh, co-chair  
Ted Goebbels, co-chair  
Mary Edwards  
Igor Krupnick  
David Lubinski  
Leonid Serebryanny  
Andrei Sher  
Douglas Siegel-Causey  
Mike Waters

***Group B***

Bill Fitzhugh, co-chair  
Ted Goebbels, co-chair  
Wendy Eisner  
Valery Astakhov  
Jonathan Bart  
Jerry Brown  
Valery Gattaulin  
Ola Johannsessen  
Gifford Miller  
John-Inge Svendsen

## SCHEDULE FOR NSF-ARCSS WORKSHOP TO DEFINE RESEARCH PRIORITIES FOR RUSSIAN ARCTIC LAND-SHELF SYSTEMS

### JANUARY 9TH EVENING

6:00-9:00 Registration and "ice breaker" at the Holiday Inn on Lane Ave.

### JANUARY 10TH MORNING SESSION: INTRODUCTIONS

8:00-8:30 Registration, coffee, and bagels

8:30-8:40 Welcome: **Ken Jezek**, Director of Byrd Polar Research Center

8:40-8:55 ARCSS-NSF perspective: **Pat Webber**, NSF-Office of Polar Programs

8:55-9:10 Workshop format: **Steve Forman** and **Len Johnson**

### 1. MORNING SESSION: RIVERINE AND SEA-ICE FLUXES (*Len Johnson, chair*)

9:10-9:25 **Leonid A. Timokhov**, PRESENT DYNAMICS OF WATER AND ICE AND THERMOHALINE PROCESSES IN THE ARCTIC SEAS

9:25-9:35 **Andrei Lapenis**, SIBERIAN RUNOFF AND GLOBAL CLIMATE

9:35-9:45 **Larry D. Hinzman** and Douglas L. Kane, THE ROLE OF HYDROLOGY IN ARCTIC ATMOSPHERIC AND OCEANIC PROCESSES

9:45-9:55 Youngsook Huh and **John M. Edmond** and Alexander Zaitsev, FLUVIAL GEOCHEMISTRY OF THE RUSSIAN FAR EAST

9:55-10:05 **Stephanie L. Pfirman**, FLUX OF SEDIMENT, WATER AND CONTAMINANTS IN THE RUSSIAN ARCTIC

10:05-10:30 **PANEL DISCUSSION**

10:30-10:45 COFFEE BREAK

### 2. MORNING SESSION: RIVERINE TO SHELF SEDIMENT FLUXES (*Stephanie Pfirman, chair*)

10:45-10:55 **Heide-Marie Kassens** and Joern Thiede, RUSSIAN GERMAN COOPERATION ON THE SIBERIAN SHELF SEAS: THE LAPTEV SEA SYSTEM

10:55-11:05 **Erk Reimnitz**, OBSERVATIONS AND SPECULATIONS ABOUT ICE-DOMINATED ARCTIC DELTAS: THE LENA RIVER, SIBERIA

11:05-11:15 **Herbert L. Windom**, WEATHERING AND MATERIAL TRANSPORT IN THE ANADYR RIVER-ESTUARINE SYSTEM

11:15-11:25 **Ray E. Cranston**, RECENT SEDIMENT AND CARBON BURIAL RATES ALONG THE RUSSIAN CONTINENTAL MARGIN

11:25-11:35 Kerry Mammone, Carolyn Viscosi Shirley, Nicklas G. Pisias, Chih-An Huh, **Peter U. Clark**, SEDIMENTATION PROCESSES OF THE LAPTEV, EAST SIBERIAN, AND CHUKCHI SEAS

11:35-11:45 Peter Vogt, **Kathleen Crane** and Christian de Moustier, SEDIMENT DYNAMICS ALONG ARCTIC GLACIATED CONTINENTAL MARGINS: SEAFLOOR IMAGING STRATEGIES

- 11:45-11:55 Sergei Drachev Leonid Savostin and **Leonard Johnson**, THE EASTERN RUSSIAN ARCTIC CONTINENTAL MARGIN: SCIENTIFIC ISSUES
- 11:55-12:20 **PANEL DISCUSSION**
- 12:20-1:15 SACK LUNCH AT BYRD POLAR RESEARCH CENTER

### **JANUARY 10TH AFTERNOON SESSIONS**

#### **1. BIOGEOCHEMICAL FLUXES AND BIOTIC SYSTEMS** (*Andrew Lapenis, chair*)

- 1:15-1:30 **John E. Hobbie** and George W. Kling, MEASURING THE FLUX OF MATERIALS FROM THE LAND TO THE SHELF
- 1:35-1:45 **Jackie M. Grebmeier** and Lee W. Cooper, BIOGEOCHEMICAL CARBON CYCLING AND ECOSYSTEM DYNAMICS IN ARCTIC MARINE AND TERRESTRIAL SYSTEMS
- 1:55-2:05 **Skip Walker**, Nancy Auerbach, Marilyn Walker, Jerry Brown, Kaye Everett, Larry Hinzman, Fritz Nelson and Natasha Moskolenko, MONITORING CHANGE IN ARCTIC TERRESTRIAL ECOSYSTEMS AT MULTIPLE SCALES
- 1:45-1:55 **Jonathan Bart** and Kent Wahl, DEVELOPMENT OF AN EIDER CONSERVATION STRATEGY: U.S.-RUSSIA SEGMENT
- 1:55-2:15 **PANEL DISCUSSION**

#### **2. GLACIAL AND SEA LEVEL HISTORY** (*Gifford Miller, Chair*)

- 2:15-2:30 **Valery I. Astakhov**, THE PLEISTOCENE GLACIATIONS IN THE WESTERN RUSSIAN ARCTIC
- 2:30-2:40 **Julie Brigham-Grette**, GLACIAL AND SEA LEVEL HISTORY OF THE RUSSIAN ARCTIC SHELVES AS A RESEARCH PRIORITY: PERSPECTIVES FROM CHUKOTKA PENINSULA
- 2:40-2:50 **Andrei Sher**, IS THERE ANY REAL EVIDENCE FOR A HUGE SHELF ICE SHEET IN EAST SIBERIA?
- 2:50-3:00 **Valery Gataullin**, KARA SEA ICE SHEET- ITS EVIDENCE ON THE SOUTH-WESTERN KARA SEA AND ADJACENT MAINLAND
- 3:00-3:10 **Steven L. Forman**, POST-GLACIAL EMERGENCE AND DISTRIBUTION OF LATE WEICHSELIAN ICE SHEET LOADS IN THE NORTHERN BARENTS AND KARA SEAS, RUSSIA
- 3:10-3:20 **Leonid Serebryanny**, QUATERNARY RESEARCH IN THE RUSSIAN ARCTIC: SEDIMENTOLOGICAL AND BIOSTRATIGRAPHICAL VIEWPOINTS
- 3:20-3:30 **Jerry Brown**, PERMAFROST PROPERTIES AND PROCESSES IN THE ARCTIC LAND-SHELF ENVIRONMENT
- 3:30-3:55 **PANEL DISCUSSION**
- 3:55-4:10 COFFEE BREAK

**JANUARY 10TH AFTERNOON SESSIONS CONTINUED**

**3. PALEOENVIRONMENTAL AND PALEOCLIMATOLOGIC ASSESSMENTS**

*(Steve Forman, Chair)*

- 4:10-4:25 **John-Inge Svendsen** and Jan Mangerud PECHORA-PALEO  
ENVIRONMENT AND CLIMATE HISTORY OF THE RUSSIAN ARCTIC
- 4:25-4:35 **Gifford H. Miller** and David J. Lubinski, RUSSIAN ARCTIC RESEARCH  
STATEMENT QUATERNARY GEOLOGY -CRYOSPHERE  
INTERACTIONS
- 4:35-4:45 **Pat Anderson**, Mari E. Edwards and Wendy R. Eisner, AN OVERVIEW OF  
PALEOBOTANICAL RESEARCH IN NORTHEASTERN SIBERIA
- 4:45-4:55 **Mari E. Edwards** and Andrei Sher, QUATERNARY HISTORY OF NE  
SIBERIAN LOWLANDS/QUATERNARY BIOGEOGRAPHY OF THE  
MAGADAN OBLAST: CURRENT WORK AND KEY QUESTIONS
- 4:55-5:05 **Wendy Eisner**, ENVIRONMENTAL CHANGE IN NORTHEAST SIBERIA: A  
MULTIDISCIPLINARY APPROACH
- 5:05-5:15 **Scott E. Ishman**, QUATERNARY PALEOCEANOGRAPHIC EVOLUTION OF  
THE WESTERN ARCTIC OCEAN
- 5:15-5:25 **Leonid Polyak**, HOLOCENE PALEOCEANOGRAPHY OF THE BARENTS  
AND KARA SEAS
- 5:25-5:35 **Lonnie G. Thompson**, Keith A. Henderson, Mary E. Davis, and Ping-Nan Lin  
SHALLOW ICE CORE RECORDS FROM FRANZ JOSEF LAND, RUSSIA:  
PRELIMINARY RESULTS AND FUTURE PLANS
- 5:35-6:00 **PANEL DISCUSSION**
- 6:00-7:30 FREE TIME AND DINNER BREAK

**JANUARY 10TH EVENING SESSION: PREHISTORIC HUMAN HABITATION  
AND MIGRATION** *(Pat Anderson, Chair)*

- 7:30-7:45 **Andrei Sher**, MAN AND MAMMOTH INTERACTION DURING THE  
DEMISE OF THE PLEISTOCENE ECOSYSTEM IN THE SIBERIAN ARCTIC
- 7:45-7:55 **Ted Goebel**, THE RECORD OF HUMAN OCCUPATION OF THE RUSSIAN  
SUBARCTIC AND ARCTIC
- 7:55-8:05 **Leonid Serebryanny**, THE EARLIEST TRACES FOR HUMAN  
MIGRATION NORTHWARDS IN EURASIA
- 8:05-8:15 **Douglas Siegel-Causey**, PALEOBIOLOGY STUDIES IN BERINGIA
- 8:15-8:25 **Michael R. Waters**, ARCHAEOLOGICAL RESEARCH IN  
NORTHEASTERN SIBERIA
- 8:25-8:50 **PANEL DISCUSSION**

***JANUARY 11TH MORNING AND AFTERNOON SESSIONS***

- 8:00-8:30 Coffee and bagels  
8:30-9:00 Goals and structure of discussion groups  
9:-12:00 'A' discussion groups convene  
12-1:00 Sack lunch at BPRC  
1-1:15 Assessment of effectiveness of discussion groups  
1:15-3:00 Exchange of discussion group members; cross fertilization  
'B' discussion groups convene  
3:00-5:30 Discussion group focus: Prioritization of research (text)  
5:30-6:00 Wrap-up discussion  
  
7:30-?: Workshop party at Steve Forman's house (1970 Inchcliff Rd. Columbus)

***JANUARY 12TH MORNING SESSION***

- 8:00-8:30 Coffee and bagels  
8:30-11:30 Presentation of discussion group chairs  
11:30-12:30 Final assessment of research priorities  
12:30-2:00 Lunch  
3:00-5:00 Celebration of the contributions of Kaye Everett at the Holiday Inn, Lane Ave.



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## AN OVERVIEW OF PALEOBOTANICAL RESEARCH IN NORTHEASTERN SIBERIA

Patricia M. Anderson

Quaternary Research Center, University of Washington, Seattle, WA 98195

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Scientists from the former Soviet Union have a rich tradition of paleobotanical research that has focused on questions of climatic histories and landscape evolution. Because of the vast territory spanned by the Russian Arctic and the great amount of previous work, we limit our discussion to northeastern Siberia, the region with which we are most familiar. The emphasis here will be with palynological data, because of their strengths in addressing issues of spatial and temporal variations in tundra and forest distributions (topic 3B).

Fossil and modern samples are required to interpret the past vegetation as well as paleoclimatic shift, the most important factor in controlling continental to subcontinent scale vegetation distributions. Interpretations of past vegetation and their associated paleoclimates (the most important factor in controlling continental to subcontinent scale vegetation distributions) require the compilation of a strong fossil and modern database. In northeastern Siberia, this database is likely to be drawn from several types of pollen depositional environments with varying degrees of spatial resolution. For example, analysis of lake sediments yield continuous records of vegetation change at the regional scale. To address questions at the landscape level, multiple peat cores should be studied for their pollen, spore and plant macrofossil content. The latter approach is advantageous when trying to understand the relationships of peatland growth, carbon accumulation, and climatic change. Correlation of the various paleobotanical records, if distributed adequately, will provide an accurate representation of past vegetation patterns. The modern database, one that is often ignored, is particularly important in these analyses because it is the basis for qualitative and quantitative interpretations of the paleovegetation types and paleoclimatic parameters.

### Fossil Studies

Pollen analysis in the former Soviet Union was viewed as a tool for biostratigraphic correlation and paleogeographic reconstruction. This work primarily concentrated on nonlacustrine sediments of the last 125,000 years. Many palynologists, such as R.A. Baskovich, M.P. Grichuk, Z.V. Orlova, B.V. Belaya, G.G. Kartashova, I.B. Kisterova, V.E. Terechova, T.D. Davidovich, I.A. Karevskaya, N.B. Verchovskaya, V.E. Narchinova, G.P. Kazakova, and T.P. Prokhorova, have contributed to the fossil pollen data set for northeastern Siberia. Their work, summarized in Shilo (1987), has focused on defining regional pollen assemblages associated with broad Quaternary glacial and interglacial cycles. The regional pollen stratigraphies suggest the complexity of vegetational patterns seen today also existed in the past. However, the poor dating control, the uneven distribution of good quality sites, and the nature of many of the deposits (e.g. colluvium, alluvium) makes only the most general comparisons of changing late Quaternary vegetation patterns possible.

The most likely time frame for documenting sufficiently detailed changes in paleovegetational

patterns and for inferring possible mechanisms of change is the last ca. 20,000 yrs. (i.e., the period when radiocarbon can provide reliable age control). A reduced data set which includes only radiocarbon dated spectra from discrete alluvial and mammoth-bearing deposits and a few lacustrine records underscores the poor resolution of paleovegetational trends throughout much of northeastern Siberia (Lozhkin, 1993, 1984; Lozhkin et. al, 1993; Shilo et. al., 1983; Sher, 1975; Yurtsev, 1984). Nonetheless, these data suggest that this region experienced a severely cold, dry climate between 27,000 and 12,500 BP with herb-dominant tundras capable of supporting mammoths and other large ungulates. At 12,500 BP, climate ameliorated with herb tundra replaced by shrub tundra, resulting in the demise of the late Pleistocene megafauna. Modern vegetation was achieved between 8000 and 5000 BP with northward extension of treeline indicating a post-glacial thermal maximum ca. 9500 to 8000 BP. Two intervals of cooler climate probably occurred between 7900 and 7500 BP and at 4500 BP.

The temperature increase during the mid Holocene led to the transformation of the landscape (Lozhkin, 1993). Degradation of permafrost following climatic warming resulted in the destructive process of thermokarst formation. As a result the Kolyma Lowland is dotted with thermokarst lakes and depressions- called "alass" in Russian. Peat started to accumulate between 9,500 and 8,000 yr BP, reaching 3 to 4 meters thickness in the alass. On the terrace and flat terrain positions away from the alass, however, peat thickness seldom exceeds 0.5 m (Ping et al. 1993). No information is yet available on peat accumulation rates or the degree of decomposition in the alass depressions during the Holocene period, although preliminary findings (see project no. 4, below) are encouraging. The acquisition of this information would provide an important trans-continental link to ongoing NSF ARCSS-LAll Flux studies on the North Slope of Alaska. The basic data-gathering and data synthesis elements of the paleostudies, listed below, also complement the PALE (Paleoclimate from Arctic Lake and Estuaries) program, which seeks to document the spatial and temporal variations in paleoclimatic proxy data as a means to improve understanding of the Arctic in global climate change.

### **Modern Pollen Studies**

In northeastern Siberia, modern pollen analyses typically have been conducted in conjunction with stratigraphic studies of ancient colluvial and alluvial exposures. Thus, the majority of modern "calibration" sites are from recent surficial soils and/or alluvial deposits. Vas'kovskii (1957) was the first to report on modern pollen spectra from different phytogeographic zones (tundra, forest/tundra, forest) in the Chukchi Republic and Kolyma basin. This early work was followed by a number of other studies in the Upper Kolyma basin (Shilo et. al., 1983; Voshilko and Kozevnikov, 1982), the Okhotsk Sea-Kolyma River divide (Federova, 1987), the northern Okhotsk Sea coast (Karevskaya, 1978; Kartashova, 1971; Borisova, 1978), the eastern and southern coasts of the Chukchi Peninsula (Davidovich, 1978), northern Chukchi Peninsula (Ter-Grigoryan, 1978); and the Novosibirsk Islands (Lozhkin, 1990).

These studies indicate that pollen spectra from forested areas are dominated by shrub pollen (i.e., *Pinus pumila*, *Alnus*, *Betula*, *Ericales*) with significant amounts of *Cyperaceae* and *Poaceae* pollen and *Sphagnum* spores. *Larix*, the dominant tree species, is either absent or represented in only trace amounts. *Populus* trees are locally abundant, but its pollen is typically absent in these assemblages. *Salix* pollen is rare, even though *Chosenia* trees and *Salix* shrubs are common in these forests. Tundra pollen assemblages are equally problematic.

Spectra from shrub tundra tend to be dominated by *Betula*, *Alnus*, and *Pinus* pollen (Vas'kovskii, 1957). These three taxa occur in all types of shrub tundra, no matter if the plants themselves are present (Lozhkin, 1990). Herb tundra is dominated by herbaceous pollen, in particular Poaceae and Cyperaceae, Compositae, Chenopodiaceae, and Ranunculaceae pollen is consistently represented. However, from 20% to 50% of herb tundra spectra contain taxa not found locally (Lozhkin, 1990). The long distance component is typically dominated by *Betula*, *Alnus*, and *Pinus* pollen.

### Ongoing Research

Cooperative, interdisciplinary paleoecological work in this region includes lake coring, peatland analysis, and combined cryopedologic and palynological research in the Magadan Oblast, the Lower Kolyma, northeastern Yacutia, and Chukotka. The following is a list of ongoing projects addressing issues of this workshop:

1. Late Quaternary Vegetation and Climate Histories of Western Beringia (National Science Foundation (ATM-9317569), National Geographic Society and the Russian Foundation for Fundamental Research) P.M. Anderson, A.V. Lozhkin, and L.B. Brubaker. The goal of this project is to describe late Quaternary climates of Western Beringia (concentrating on areas in Anadyr basin, northern Chukotka and Wrangel Island, the upper Kolyma and the Indigirka drainage) as inferred from lake pollen and macrofossil records. Project began in 1989 will be completed in 1998.
2. Quaternary Paleoenvironments of Magadan Oblast and Chukotka (Russian Academy of Science) A.V. Lozhkin and O. Glushkova (Magadan) and A. Kotov (Anadyr). Ongoing research of the Quaternary Laboratory of the North East Interdisciplinary Research Institute, Magadan, and the Scientific Research Center, Anadyr, using multiproxy indicators of past environments and climates.
3. Pollen Database for Eastern Sectors of the Former Soviet Union (National Oceanic and Atmospheric Administration) P.M. Anderson, A.V. Lozhkin, and M. Trumpe. Project to begin in fall, 1995 to compile an annotated pollen database for eastern areas of the Russian Federation. To be completed in 1998.
4. Environmental change in Northeast Siberia: A Multidisciplinary Approach. (National Geographic Society--5240-94) W. R. Eisner and C. L. Ping. Late Quaternary Vegetation History and Depositional Environment of the Yedoma Sections of the Lower Kolyma; Northeast Siberia--Feasibility Study (National Science Foundation-OPP-90500240) W. R. Eisner. The project combines cryopedology (frozen soil analysis ) with pollen, spores, and other microfossil analyses of the Lower Kolyma River terrace deposits.
5. Paleoecological Analysis of Late Quaternary Sections, Lower Kolyma. (Russian Academy of Science, University of Alaska). M.E. Edwards, A.V. Sher, and A.V. Druk. This project focused on the study of paleoenvironmental indicators from dated sections of yedoma and alass deposits to better understand full- and late-glacial landscapes and environmental conditions. Field work was completed in 1992, although analyses of the collected material is continuing.

Although not specifically working in northeastern Siberia, an ongoing Canadian-Russian



cooperative project, PACT (Palaeoecological Analysis of Circumpolar Treeline), should be acknowledged. Sampling in northwestern and north-central Siberia, these researchers have cored lake and peat deposits in transects across current treeline. They are looking at multiple indicators of past vegetation and climatic change, such as pollen and other microfossils (e.g., diatoms), plant macrofossils, and lake geochemistry.

The Paleogeography Lab, Moscow, is beginning to compile a pollen database for eastern and central regions of the former Soviet Union. The field and laboratory work is funded by the Natural Sciences and Engineering Council of Canada and the Russian Academy of Science. It is vital that any efforts by U.S.- based researchers should minimally contact, and preferably include the PACT group.

### **Future Directions and Concerns**

Understanding any of the earth's systems of the past, not only those of the Arctic, involves three steps: 1) the documentation of past events and patterns; 2) the evaluation of the data used to infer these reconstructions; and 3) the search for mechanisms which explain the observed patterns. The first two steps involve the compilation of existing databases for ready computer access, the determination of key areas or times where data are lacking (i.e., defining the spatial and temporal limitations of the existing database), the definition of the most effective analytical techniques (e.g., analog analysis, response surfaces) and definition of ways to incorporate multiproxy paleoenvironmental data sets in a meaningful way (e.g., constrained analogs). The second element focuses on the comparison of data-based interpretations with conceptual and/or numerical models.

Important improvements have been made by PALE to standardized field and laboratory protocols (published in both English and Russian; PALE Steering Committee, 1993). Increased contact with the major centers for pollen databases (e.g., the European and North American Pollen Databases) has also initiated the compilation of results from decades of work in the Soviet Arctic. Because of the ambitious goals of this work, we suggest that any science plan include statements of research that have relatively modest, achievable goals, which can then be built upon for more integrative multiproxy syntheses and interpretations. Although "big picture" questions can and should be addressed in this workshop, the reality of the existing and potential data to be collected over the next decade must be kept in mind when defining key research questions or goals.

We urge that three points be addressed in our discussions:

1. A frank recognition of modeling and sampling limitations in the Eurasian Arctic is a vital first-step in establishing a strong foundation for a science initiative. For example, is it reasonable to expect a reasonable grid of fossil and modern sites, such that state-of-the-art paleovegetation or paleoclimatic analyses can be done? If not, what are the appropriate analytical methods? Although defining controls of paleovegetational patterns is certainly a central issue for describing the past arctic earth system, is it even possible to define detailed late Quaternary vegetation histories of the Russian Arctic, given the complex nature of the coastal and lowland deposits?
2. Any work in this region must be cooperative with the scientists in Russia, Yakutia, and

Chukotka. These researchers have spent decades of hard work collecting and analyzing data. A number of permanent and semi-permanent scientific research stations are currently in place in the Eurasian Arctic which are capable of providing invaluable logistic, staff and scientific support. These stations could be maintained and utilized with a minimum of outside support. How can we from a practical standpoint be both cooperative and supportive given the devastating effects of the country's economy on the scientific infrastructure?

3. At least for the terrestrial paleoenvironmental studies, it would be advisable to expand the study area from the coastal plain to areas north of 60°N latitude. To understand both past environments and climates of the current tundra region, it is necessary to examine a broader geographical region. 60°N latitude is suggested to parallel criteria established by PALE.

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## THE PLEISTOCENE GLACIATIONS IN THE WESTERN RUSSIAN ARCTIC

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The Russian Arctic west of 110° 8'E was fully glaciated during all known ice ages except the Late Weichselian. Only the western part of the Russian Plain (west of 50° 8'E) was subjected to Scandinavian glaciations. East of this line inland ice was mostly dispersed from shelf sources and partly from the high plateaux of the Mid-Siberian Uplands. The thickest, up to 3.5-4 km, inland ice apparently developed during the pre-Eemian glacial maxima when ice sheets spread down to the 50th parallel in European Russia and 60th parallel in Siberia. The ice thickness estimates are confirmed by thicker tills and higher position of far-travelled erratics in adjacent mountains. During the two or three pre-Saalian glaciations ice sheets were not smaller but probably somewhat thinner due to milder glacial climates.

The thick pre-Eemian ice sheets caused the drastic reconstruction of the megarelief and appearance of the uppermost structural stage of highly contorted rocks up to 300-400 m thick. The sedimentary basins attacked by such glaciers lost a huge volume of surficial Meso-Cenozoic rocks to acquire buried valleys overdeepened down to 350 b.s.l. The repeated glacial loading caused deep unretrievable sinking of the sedimentary basins and emergence of compensation horsts several hundred meters high. This was the major tectonic event in the entire Meso-Cenozoic history which also induced redistribution of petroleum reserves.

The most salient evidence of the thickest Saalian ice sheet is the very high position of the Eemian marine strata of the Boreal Transgression. Their most common altitudes are 40 to 60 m a.s.l., being up to 130-150 m on some isostatically uplifted blocks and even higher on Novaya Zemlya islands.

Ice sheets that developed in the post-Eemian were much smaller due to the progressive aridification. The Early Weichselian glaciers hardly reached the Arctic Circle, having shrunk by 800 km in Siberia and more than 1800 km in European Russia as compared to the Pleistocene maximum ice limit. Accordingly, their thickness could not exceed 2.5 km on the shelves and was much less on the mainland. This is evidenced by the absence of the uplifted shorelines on the mainland coasts.

Even less extensive were the Late Weichselian glaciers, mostly limited to the arctic islands. There still exists the problem of extent of the Late Weichselian ice in the eastern Barents Sea. Terrestrial data would rather suggest smaller glaciers confined to Novaya Zemlya and neighboring shelf, but marine geologists seem to prefer a large ice dome centered upon the deepest Barents shelf. This issue, if solved, would help to considerably elucidate many preceding glacial events, especially the rather dark history of the ice dispersal paths.

The most peculiar feature of the Arctic glaciations is the mode of their degradation which is governed by the proximity of the ocean and ubiquitous permafrost. Fast rise of sea level led to rapid disintegration of the shelf-centered ice sheets, but the solid permafrost facilitated preservation of stagnant and buried ice remnants for tens of millennia. There are good examples

of the retarded deglaciation from the Yenissei and Pechora valleys. This process along with the very soft substratum burdens investigators with the problem of distinguishing between true signatures of ice advances and various pseudo-tills formed during the retarded deglaciation.

This difficulty coupled with the widespread redeposition of organic matter by lowland-centered glaciers hinders notably the progress in research, especially in timing principal ice advances. It seems that the conventional radiocarbon method should be used in the Russian Arctic with great reservations, only on a very sound sedimentological basis. At the present state a reliable correlation signal can only be inferred statistically from scores of radiocarbon datings.

## DEVELOPMENT OF AN EIDER CONSERVATION STRATEGY: U.S.-RUSSIA SEGMENT

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Kent Wahl, U.S. Fish and Wildlife Service

### Introduction

The four species of eiders (common eider, *Somateria mollissima*; king eider, *S. spectabilis*; spectacled eider, *S. fischeri*; Steller's eider, *Polysticta stelleri*) have been the source of considerable concern during the past several years. As a result, a proposal was made by the US delegation to the Conservation of Arctic Flora and Fauna (CAFF) working group to develop an eider conservation strategy. The proposal was favorably received and is being undertaken by the Seabird Working Group. Much of the work will involve collaboration with Russian scientists.

### Objectives/Benefits

Develop a conservation strategy for the four eider species following the approach developed by the CAFF Circumpolar Seabird Working Group in preparing the murre conservation strategy.

### Proposed Work and Duration

(1) Identify one or more contacts in Russia for this project. (2) Gather and summarize information on the abundance, distribution, and status, and on research and monitoring efforts, on the four species. (3) Determine goals and priorities for eider conservation. (4) Develop an integrated, arctic-wide strategy, following the approach developed for the murre conservation strategy, and including sections on current status and conservation problems, trends, specific steps to be taken, implementation schedule, and funding needs. (5) Present the strategy described above to CAFF for consideration and possible adoption.

### Funding

National Biological Survey, U.S. Fish and Wildlife Service.

## **DEVELOPMENT OF MONITORING PROGRAMS FOR CAFF INDICATOR SPECIES: U.S.-RUSSIA SEGMENT**

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### **Introduction**

The Conservation of Arctic Flora and Fauna (CAFF) Working Group has developed a list of species to be monitored as indicators of broad-scale change to Arctic ecosystems and has recommended that the list be used to facilitate: 1) coordination of monitoring and research activities throughout the Arctic; 2) calibration of reporting procedures and compatibility of data between countries; and 3) focussing Arctic research and monitoring on issues and/or species of broad international concern. To help achieve these goals, the U.S. delegation to CAFF proposed development of methods to be used in monitoring the indicator species. The proposal was favorably received and is being undertaken by the Seabird Working Group. Much of the work will involve collaboration with Russian scientists.

### **Objective**

Develop an integrated, arctic-wide monitoring program for selected species from the CAFF list of indicator species.

### **Proposed Work and Duration**

(1) Identify one or more contact persons for this project in Russia. (2) Identify 3-5 species, in addition to murres and kittiwakes, for study. (3) Compile and summarize information on trends and existing monitoring programs for the selected species. (4) Develop one or more options for integrated monitoring efforts specifying what new programs, if any, would be needed in each country, how information from different efforts would be combined, reporting schedules, likely benefits of the program, and funding requirements. (5) Present the plan described above to CAFF for consideration and possible adoption.

### **Funding**

National Biological Survey, U.S. Fish and Wildlife Service.

## GLACIAL AND SEA LEVEL HISTORY OF THE RUSSIAN ARCTIC SHELVES AS A RESEARCH PRIORITY: PERSPECTIVES FROM CHUKOTKA PENINSULA

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### General Commentary

Significant questions persist concerning the extent of ice sheets across the Russian Arctic, not only during the Last Glacial Maximum but during earlier episodes of glaciation as well. The glacial record from the Yukon and northern and western Alaska indicate that the LGM was not necessarily the most extensive across the western Arctic and that changes in both oceanic and atmospheric circulation, especially during parts of the middle Pleistocene, nourished glacial systems in a manner not reproduced during the latest Pleistocene (c.f., Roof and Brigham-Grette, submitted). Russian researchers working across eastern Siberia and the Chukotkan region document a similar pattern of glaciation with limited ice growth during the LGM, despite the theoretical modeling of large ice masses across parts of the Russian Arctic by Grosswald (1988, *Polar Geology and Geography*) and now Hughes and Hughes (1994, *Paleo3*).

Continuous or nearly continuous records of climate and sea level change will likely come from long cores retrieved from the Russian shelves (including the Chukchi and Bering platforms), but these data must be complemented by discontinuous records of relative sea level change (especially raised shorelines) found only in coastal regions. The glacial record of adjacent land areas is also critical for understanding the impact of glacial/interglacial cycles on shelf erosion and sedimentation. It seems likely that accurate maps of both marine and non-marine glacial ice extent, especially for the past 500 ka, from the Barents Sea to the Chukchi and Bering Sea will tell us a great deal of changing moisture sources, the distal influence of the Gulf Stream, and changes in atmospheric circulation. Why was glacial ice extent so radically different in the western Arctic during the middle Pleistocene?

The tectonic framework of the Russian Arctic is of interest, especially where the Arctic Basin rift enters the Laptev Sea and comes ashore. This will, no doubt, be covered in detail by others at the workshop. But in this context, we still lack a clear understanding of the early tectonically (?) driven submergence history of the Bering Strait and how the intermittent oceanic linkage between the Arctic Basin and the North Pacific may have influenced global ocean circulation through time. Although traditionally the first Cenozoic submergence of the Bering Strait has been placed at about 3.0 Ma based on stratigraphic work on northern Iceland, recent work by Gladenkov and others indicates that the first submergence recorded on the Russian coast may have been about 4 Ma. Moreover, the discovery of Miocene marine sediments containing Pacific endemic diatoms on the east Siberian coast leads to the suggestion that the first submergence may have been much earlier and/or that a Miocene marine gateway (?) between the Arctic Basin and Bering Sea may have been at a different location across northeast Russia (Gladenkov, pers. comm., July 1994). Furthermore, warm Pliocene high sea levels recorded in northern Alaska, the Arctic Islands, and coastal Greenland are also likely recorded along parts of the Russian arctic coast, but so far these deposits have received little attention or are poorly dated. On more recent timescales, ocean modelers have made the case that changes in the amount of water flowing northward through the Bering Strait during high sea level events may have caused thermohaline circulation in the Norwegian/Greenland seas to be sensitized to other

forcing factors.

### **Ongoing Russian Research**

Joint field work with Russian colleagues from the North East Science Center (Magadan) and the Geological Institute (Moscow) of the Russian Academy of Science was initiated in 1991 as part of a three year project to develop a new stratigraphic framework for the late Cenozoic glacial and sea level history recorded on both sides of the Bering Strait. Despite the ever changing political and economic conditions within Russia and the Russian Academy, our Russian colleagues persevered in obtaining funding for field work on the coast of Chukotka Peninsula in both 1991 and 1992, although it was not possible to visit all desired type sections as originally planned. Field work on the Alaskan side in 1991 and 1993 ensured that most of the major stratigraphic sequences in the Bering Strait region were jointly visited and sampled for biostratigraphic and geochronologic study.

The results of this project suggest that the glacial and sea-level history of Chukotka Peninsula needs to be drastically revised. In the past, the regional stratigraphic scheme compiled by Russian geologists for the coast of Chukotka Peninsula was based upon fossil faunal assemblages (including mollusks, foraminifera, and diatoms), topographic position (that is, height above sea level), stratigraphic sequence, differences in assemblages of detrital minerals, and at one section, sparse, incompletely documented paleomagnetic data. We found that this stratigraphic approach involved antiquated concepts of sedimentology, biostratigraphy, and tectonics. For example, fossil assemblages assumed by our Russian colleagues to be stratigraphic markers appear to us to be markers of specific ecological situations (lagoon, open deep water, etc.); they include few or no extinct forms and very few extralimital forms. In addition, some of our Russian colleagues seem to be unfamiliar with the likelihood of an isostatic response along coasts overridden by glaciers, and they seem to be oblivious to the extremely striking glaciotectonic effects observed in several sections that we visited (previous workers at one section wrote of submarine sliding or permafrost related cryogenic structures). Most importantly, the Russian stratigraphic approach has been complicated and obscured by inadequate geochronological techniques of utility beyond the range of radiocarbon dating.

Publication of our results beyond abstracts at numerous national meetings has been delayed due to resolute differences in opinion over the age of several jointly studied sections. The last year has been spent completing additional analyses to test the different age models. A large portion of our results are now compiled in Brigham-Grette et al. (in press), and other related papers are in preparation now that all collaborators have agreed to jointly author papers which present both sets of interpretations.

Major revisions to the stratigraphic scheme of Chukotka Peninsula are outlined below:

1. The Pinakul Suite at Cape Pinakul, previously thought to be of early Pleistocene age, dates from parts of the last interglacial, or marine isotope stage 5 (130-70 ka). Amino acid geochronology, strontium analyses on shells, new biostratigraphic work, and new paleomagnetic work are consistent with the younger age interpretation. Field work by Benson (1993; Benson, 1994) at the same sections has demonstrated that structural deformation of the sequence was caused by one episode of glacial overriding, not cryogenic forces as suggested earlier.
2. The Pinakul Suite is younger, not older than beds assigned to the Yanrakinot Suite at Cape Pinakul. The so-called Yanrakinot Suite at Cape Pinakul beds is clearly glaciomarine in



sediment character and may not be the same age as the middle Pleistocene marine Yanrakinot Suite at its type section some 100 km to the south.

3. The Val'katlen marine section at the Enmelen River representing the last interglacial and the presumed middle Pleistocene Mechigmen beds exposed 20 km to the north near the Nunyamo River are, in fact, similar in age and both date from portions of the last interglacial. We have reinterpreted the entire section of interbedded marine and glaciogenic deposits as a complex sequence related to glacial advance and isostatic loading during marine isotope stage 5 and stage 4. Previous workers had attributed every marine bed and every glaciofluvial bed in the Nunyamo sequence to separate events dating back into the middle Pleistocene based primarily on sequence above sea level, without any consideration of loading history.

5. Glacial ice from Chukotka Peninsula advanced out onto the Bering Shelf and terminated against northwest St. Lawrence Island at least twice in the past. The older event occurred during the middle Pleistocene, deformed and overrode marine sediments correlative with the Anvilian transgression defined at Nome, Alaska (likely marine stage 11), and is probably correlative with the Nome River Glaciation on Alaska's Seward Peninsula (Kaufman et al., 1991). Ice advanced again during the early Wisconsinan and deformed last interglacial beach deposits. Based on the field work of Heiser (Heiser et al., 1992; Heiser and Roush, 1994; Heiser, Ph.D. Univ. of Alaska, in progress) the ice did not extend far inland on the island. Cirques at the southwest corner of the island supported small valley glaciers during the early Wisconsinan. Late Wisconsin glacial ice accumulation on St. Lawrence Island was limited to only small cirque glaciers in the Kongok Basin and local rock glaciers.

As a part of this project, shell samples from the classic late Neogene to early Pleistocene sequence on Karaginsky Island and from early Pleistocene sections nearby on Kamchatka Peninsula were analyzed for amino acid geochronology. These sequences are otherwise dated by diatom biostratigraphy, paleomagnetic data, and a few fission track age estimates; hence the results are important for calibrating amino acid data from the Russian side of the Bering Sea. These data were completed over the last year and joint publications are in preparation.

### **International Considerations**

Shared problem-solving among scientists builds trust, friendship, and an appreciation of cultural differences. Clearly, study of the Russian Arctic can only be carried out in a cooperative mode with Russian scientists. However, national differences in sedimentologic and stratigraphic terminology and in sedimentological and geomorphical concepts, make it necessary for both Russian and American scientists to work together -- in the field and in the laboratory.

An important benefit of working together will be the opportunity to expose Russian scientists to techniques not readily available in their country, particularly geochronological methods. A major task for all of us will be convincing our colleagues of the usefulness of these techniques, even when our results contradict stratigraphic ideas and relationships that they have not questioned themselves. By all means we must avoid any perception that we are forcing western-style techniques and concepts on them, rather we should hope to work with the Russians by sharing field and laboratory techniques. This is a sensitive issue that cannot be overstated.

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## PERMAFROST PROPERTIES AND PROCESSES IN THE ARCTIC LAND-SHELF ENVIRONMENT

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Perennially frozen ground (permafrost) is present throughout the Arctic shelf and land-based regions of the Russian and North American Arctic. The vast majority of deep-seat permafrost formed during past glacial periods and on the shelf when it was exposed to subaerial environments. Its distribution and properties are better known on land where it occurs under all of these northern land masses to depths commonly exceeding 500 meters. The distribution of permafrost on the shelf is less well known, but generally considered to exist extensively on the broad expanses of continental shelf and near-shore environments.

The shelf-coastal land regions of Northwestern North America and the Russian North have much in common and warrant continued, joint comparative studies in order to further our understanding of both regions. In the Northwestern North America Arctic, there are several notable examples of programs of land-shelf interactions to draw upon (Outer Continental Shelf Environmental Assessment Program, the Prudhoe Bay environmental studies, the Canadian Beaufort Sea and Mackenzie River projects, and several long-term studies of the Colville River and adjacent estuaries and shelf region). In addition, a heritage exists of collaborative research between these two regions; for example, past and on-going studies of Beringia and Bering-Chukchi seas. This proposed initiative is a logical extension of these and similar examples of international scientific collaboration.

Permafrost is important to studies of modern-day processes and paleoenvironments. It contains and preserves details of thermal and stratigraphic records. The presence of buried and near-surface massive ground ice is indicative of climatic and related near-surface geomorphic processes. The low permeability of permafrost terrain is an important element in terrestrial water balance and the contribution of fresh water to the shelf and Arctic Basin. The movement of solutes and contaminants over, within and beneath the permafrost is poorly understood and extremely important in the assessment Arctic contamination. Permafrost sustained high-water tables, the abundance of organic-rich soils and permafrost, trapped trace gases in buried ground ice, and abundant presence of gas hydrates are important potential contributors to trace gas emissions. The presence and susceptibility of ice-rich permafrost in the coastal zones to accelerated erosion are important considerations for the occurrence of off-shore permafrost and the paucity of near-shore archeological sites. Economic development and environmental protection in these coastal zones are in a large degree influenced by permafrost. Vast quantities of the world's hydrocarbon and reserves are located in these regions. The permafrost environments and their unique fauna, flora, habitats and ecosystems can limit access to resource development.

In recognition of the opportunities and constraints for research in these permafrost environments, the U. S. Academy of Sciences under its Polar Research Board issued a series of reports in the 1970s and early 1980s. Selective recommendations of the following reports are clearly relevant to the workshop objectives and should be considered: (1) Priorities for Basic Research on Permafrost (1974); (2) Opportunities for Permafrost-Related Research

Associated with the Trans-Alaska Pipeline System (1975) (3) Problems and Priorities in Offshore Permafrost Research (1976); and (4) Permafrost Research: An Assessment of Future Needs (1983).

Many scientific questions will be raised that depend on a good working knowledge of the extent and properties of on-shore and off-shore permafrost. Although many maps and numerous monographs and publications exist, maps utilizing an accepted international legend and at an appropriate international scale are almost non-existent. The draft IPA circumarctic permafrost map (1:10,000,000) will be available at the workshop and its use and limitations can be discussed. Also available will be a newly prepared permafrost map of the Russian Arctic (north of 64° N latitude at a scale of 1:7,500,000). An accompanying text contains descriptions of the cryogenic physico-geological processes (CPGP) for the seven subprovinces of the Russian Arctic (Arctic Islands, European North, Urals, Western Siberia, Eastern Siberia, Northeast Siberia and the Far East).

In the past, international approaches to permafrost research have lacked truly integrated approaches. However recently, international collaboration in the investigation of permafrost and cold-dominated soils (cryosols) has accelerated through working groups and joint activities of the International Permafrost Association (IPA) and other global change activities including the Japanese-Russian Siberian program, International Tundra Experiment (ITEX), etc. Several of the IPA activities could be utilized to further develop the overall planning and implementation of this initiative. These include joint mapping programs for both on-shore and off-shore permafrost and soils so that the same units and attributes can be delineated in the areas of common interest. Similarly, the same or equivalent terminology should be agreed upon and used. And most important, easier access to past and current data, much of it still contained in original publications or files, should be encouraged and developed. The IPA Global Geocryological Database and other paleoenvironmental databases (PALE) should be integrated into the program plan.

## SEDIMENTATION PROCESSES OF THE LAPTEV, EAST SIBERIAN, AND CHUKCHI SEAS

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We are studying the distribution of modern sediments across the broad and shallow continental shelves underlying the Laptev, East Siberian, and Chukchi Seas bordering central and northeastern Siberia and northwestern Alaska. We are using samples from over 200 sediment cores collected from these shelves over the last 3 decades. Our main goals are to (1) understand sedimentation processes on these shelves and (2) define the pathways and rates of particulate sediment transport across the shelves. This understanding of contemporary processes and provenance will be important for recognizing past oceanographic changes affecting the shelves as well as evaluating the pathways of radionuclide transport along this margin of the Arctic Ocean.

Thus far, we have analyzed 69 core-tops from the Chukchi (26), East Siberian (17) and Laptev (26) seas for grain size, weight-percent biogenic silica, and major and minor element chemistry. We have also measured the downcore magnetic susceptibility of 50 cores. Sediment accumulation rates have been estimated for nine cores from Pb-210 dating. AMS C-14 dating of 17 samples of macrofossils (molluscs) from the Chukchi Sea unexpectedly identified some source of contamination so that all the samples except two are fraction modern (FM) ranging from 0.9 to 5.7 FM; we have not yet identified the source of the contamination. Additional work on the cores will involve measurement of clay mineralogy and organic carbon of core-top sediments as well as further study of downcore variability in chemical, mineralogical, and sedimentological data. We will then begin statistical modeling of the data to evaluate the distribution, provenance and transport of sediments on these shelves.

## SEDIMENT DYNAMICS ALONG ARCTIC GLACIATED CONTINENTAL MARGINS: SEAFLOOR IMAGING STRATEGIES

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The Russian Arctic shelf-Arctic Ocean regime is known to harbor a host of geological phenomena including active and extinct spreading centers, intermittently glaciated margins, and a variety of sedimentary regimes. However, in the absence of systematic swath bathymetric and acoustic backscatter imagery mapping, the 2-D (area) resolution of seafloor maps remain no better than 10's of kilometers except in a few localized areas. As a result, a number of sediment-dynamic processes remain at best poorly characterized in this region.

Where side-looking sonar has been used to image parts of the Barents Sea and Svalbard shelf and shelf break, a number of sediment-dynamic phenomena were discovered which were in some cases entirely unknown or unexpected. Furthermore, in every case, new questions about the physics of the processes that have shaped these intermittently glaciated margins have been raised.

Noticeable features discovered were about two dozen sediment mud-debris flows (on the Bear Island Fan) which extend up to 200 km from the shelf edge to the Mohns Ridge in the Norwegian-Greenland Sea. Prior to imaging by the SeaMARC II (11-12 kHz) system in 1989, these features were described as "sharp continuous returns with one or two uncomformable wedging sub-bottom reflectors" by Damuth (1978) and which he suggested were evidence for "downslope sediment progradation via gravity-controlled mass flows". Vorren et al. (1989) associated these mudflows with glacial advances to the shelf edge, with each mudflow packet representing a shelf-edge glacier advance of the Barents ice sheet. If this interpretation is correct, the nature and timing of mudflow activity may relate to the nature and timing of the almost totally marine Barents Sea ice sheet. The mudflows may therefore be important not only as a class of mass-wasting on glaciated margins, but also as a paleoclimatologic/paleoglaciological index. Whether or not other large troughs cutting the Russian shelves are sites of similar styles of mass wasting can only be confirmed by large-area acoustic surveys.

Also detectable by side-looking sonar surveys are sediment waves, indicative of bottom currents and possibly winter water formation sites, time-transgressive redistribution of estuarine and deltaic environments in the near shore regions, exact locations and extent of recently active and extinct channels, ice rafting, iceberg plow marks, methane generated pockmarks, mud volcanoes, uniform pelagic sedimentation, sea level changes, basement outcrops, and sub and pro-glacial processes such as chaotic elevated ridges (moraines), subglacial channels and parallel grooving, etc.

Different types of acoustic and optical instrumentation can be utilized to reveal geological processes of different scales. Wide-swath mapping systems such as the SeaMARC II (no longer in existence) and the SEAMAP return from 10 -20 km wide side-looking sonar imagery

(respectively) in tandem with 50m bathymetric contours. These systems are not hull mounted and must be towed behind the ship at speeds of approximately 8 knots. Newer systems such as the SIMRAD EM-12D, and the SeaBeam 2000 have a much higher resolution bathymetry (10 m contours), incorporated with side-looking sonar imagery that is calibrated and geometrically correct. However, these systems do poorly in ice covered, shallow-water terrain.

Multibeam echosounders now exist for shallow water regimes ( <1,000 m depth). For example the Simrad EM1000 and EM950 systems both return detailed bathymetry and side-looking sonar imagery with swath widths of up to 7 times water depth. In addition, the RESON SEABAT system, operating at 450 kHz and at water depths of <100 meters, can be put on an ROV, or hull mounted or attached to a towfish, thus increasing the portability of the operation. Survey speeds are also considerably higher, a factor which may be significant in regions that are ice-covered during most of the year.

If surveys require spatial resolutions in the meter-centimeter range, then systems which contain both sidescan and optical imaging such as the Scripps Deep-Tow Instrument, are ideal. However, deep-towed systems often require the additional use of seafloor moored acoustic transponders for high resolution navigation. On the positive side, the resulting near-bottom, high-resolution swath bathymetry which provides accurate topographic maps in 1m contours can answer questions such as: What are the amplitudes and slopes of the bedforms? What are the relationships between local topography and features such as sediment ripples and current directions? Sidescan sonar imagery can also yield scattering strength variability and may well discriminate between current ripples, rock/gravel, vs sand or silt/mud. Subbottom profilers mounted on deep-tow systems reveal the internal structures and spatial/temporal relationships within the sediment waves and underlying channel deposits. Such data may help to discriminate between the age of the sediment waves, and which direction the sediment waves are migrating relative to the regional bathymetry, and the internal structure of channel deposits and relic vs presently active bedforms such as sediment ripples caused by ancient or present bottom currents. Finally, optical imaging and photogrammetry can image sediment ripples and possibly shorter sand waves and their spatial characteristics, particularly microtopographic contours.

Experience from the Barents Sea and the margins of Svalbard suggest that depending upon the degree and duration of ice cover in the region to be surveyed, as well as the range of water depths, surveys should be designed to first map large regional features, providing base maps for future detailed coring, dredging, other sampling programs, and deep-tow measurements. Otherwise, coring surveys risk misinterpretation and spatial aliasing and major geological processes pertinent to the glacial history of the Arctic shelves may go unnoticed.



## RECENT SEDIMENT AND CARBON BURIAL RATES ALONG THE RUSSIAN CONTINENTAL MARGIN

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### Introduction

The Russian continental margin contains the largest continental shelf in the world which has for decades been classified as 'out of bounds' to foreign researchers for strategic reasons. As this new area becomes available to researchers, comparisons between Russian and North American arctic coastal regions can be made.

Efforts are required to understand present day marine processes and budgets such as river discharge of water and sediment, ocean circulation, biological productivity, ice cover and ice movement. One of the key present day components to measure is the accumulation rate of sediment and organic carbon throughout the continental margin.

Historical evidence of variations in sediment accumulation rates [measured by conventional chronological methods: isotopic, paleontological, amino acid, etc.] can be compared with the present day accumulation rates and other present day conditions and processes. Significant variations in accumulation rates in the sediment column are due to changes in historical conditions and processes (e.g. sea and land ice cover, river discharge, ocean circulation, productivity, etc.). In order to unravel the history held in the geological record, it is fundamental that present day accumulation rates and processes be understood. This abstract outlines a new approach to measuring recent sediment accumulation rates which are in equilibrium with present day processes.

Deep sea sediment columns often receive limited amounts of organic carbon, resulting in low carbon burial rates and organic carbon concentrations. In coastal areas where increased amounts of organic matter reach the sediment, more organic mineralization occurs in the sediment column. This increases the rate that ammonium is released to and that sulfate is consumed in the pore water. The purpose of this abstract is to present a method which estimates present day sediment burial rates using ammonium and sulfate concentration-depth variations (Cranston, 1991a; Cranston, 1994a). Results to calibrate the method are summarized from more than 100 sites, based on organic carbon measurements and sediment accumulation rate estimates from isotopic, biostratigraphic and observational data.

### Methods

Ammonium and sulfate gradients are measured by collecting sediment cores and removing pore water at selected intervals downcore. About 40 ml of wet sediment is selected from each depth interval and placed in a 50 ml plastic centrifuge tube. The samples are centrifuged at 6000 g's in a 4 °C cold room. The pore water is decanted off the sediment and filtered through 1 µm pore diameter filters.

Ammonium is measured using a standard colorimetric method (Solorzano, 1969). The method requires between 0.1 and 2 ml of pore water, depending on the concentration of ammonium. Sulfate is measured in 50 µL of pore water with a turbidity method which uses barium chloride

to precipitate sulfate. The amount of turbidity is a measure of the amount of BaSO<sub>4</sub> precipitate.

Within 4 hours of collecting a core, ammonium and sulfate profiles can be obtained which provide an immediate estimate of the carbon and sediment burial rate. Pore water samples can be frozen and stored for months with minimal degradation to the results.

#### **Calculating Sedimentation and Carbon Burial Rates**

The sulfate and ammonium gradient relationships with sediment burial rate (SBR) and carbon burial rate (CBR) can be summarized with the following equations (Cranston, 1991a; Cranston, 1994a): 1)  $SBR [cm/1000 \text{ years}] = (10) \times (-\text{Sulfate Gradient})[mM/m] / \text{Organic carbon } [\%]$  (for example, if the sulfate gradient is 10 mM/m and average organic carbon content is 2%, the estimated sediment burial rate is  $(10 \times 10 / 2 = 50 \text{ cm/1000 years})$ ; 2)  $SBR [cm/1000 \text{ years}] = (100) \times (\text{Ammonium Gradient})[mM/m] / \text{Organic carbon } [\%]$  (for example, if the ammonium gradient is 5 mM/m and average organic carbon content is 5%, the estimated sediment burial rate is  $(100 \times 5 / 5 = 100 \text{ cm/1000 years})$ ; 3)  $CBR [g \text{ C } m^{-2} d^{-1}] = (0.0024) \times (-\text{Sulfate Gradient})[mM/m]$  (for example, if the sulfate gradient is 10 mM/m, the estimated carbon burial rate is  $(0.0024 \times 10) = 0.02 \text{ g C } m^{-2} d^{-1}$ ); 4)  $CBR [g \text{ C } m^{-2} d^{-1}] = (0.023 \times (\text{Ammonium Gradient})[mM/m])$  (for example, if the ammonium gradient is 5 mM/m, the estimated carbon burial rate is  $(0.023 \times 5 = 0.1 \text{ g C } m^{-2} d^{-1})$ ).

#### **Application of Method**

A recent trans-arctic expedition (July-Sept. 1994) using Canadian and American icebreakers provided an opportunity to apply the method to measure carbon and sediment burial rates (Cranston, in prep.). In the open basins of the western Arctic Ocean, sediment accumulation rates were  $<0.3 \text{ cm/ka}$ . As the North Pole was approached, sediment and organic carbon accumulation rates appear to increase by an order of magnitude. Discussions with physical and biological oceanographers involved with the expedition will be carried out to verify these findings.

In another recent field operation in Montevideo harbour in Uruguay (October 1994), cores were collected and processed using the above techniques (Cranston and Kurucz, in prep.). Past attempts to estimate accumulation rates for this shallow, highly dynamic area, using carbon, lead and cesium isotopes were unsuccessful due to intense mixing in the sediment column. Based on initial organic carbon results, the inner harbour is collecting sediments at the rate of 3 mm/year, while the outer harbour rate is 2 mm/year.

The method was applied to a study carried out with Russian researchers in the Sea of Okhotsk in 1991 (Cranston, 1991b; Cranston and Standing, 1992; Cranston et al., 1994; Ginsburg et al., 1993). This study also showed the impact that gas vents and gas hydrate deposits can have on carbon budgets. Gas hydrate deposits in the arctic may pose a threat if global warming allows for significant amounts of methane to be released from hydrate deposits (Cranston, 1994b).

Using the method for the continental margin off Nova Scotia (Cranston, in prep.), carbon and sediment burial rates have been measured for coastal inlets, the shelf, slope (200 to 3000 m), rise (3000 to 4500 m) and deep sea. Based on an estimate for carbon and sediment budgets, coastal inlets collect 4% of the organic carbon and 0.5% of the sediment being deposited along a transect. The shelf, including small depositional basin on the shelf, collects 32% of the carbon

and 35% of the sediment being buried. The slope captures 21% of the carbon and 13% of the sediment, while the rise collects 7% of the carbon and 8 % of the sediment. The deep sea area receives 37 % of the carbon budget and 43% of the sediment budget. Sedimentation rates vary from 5 cm/ka in deep water to >100 cm/ka in inlets. A comparative study along the California margin has been reported by Reimers et al. (1992) however the accumulation rates are based on very few carbon isotope determinations which may have little bearing on present day accumulation processes.

### New Avenues of Research

The proposed method will provide immediate estimates of accumulation rates which can be used to establish carbon and sediment budgets for the Russian continental margin. What fraction of the total sediment load is captured by the immense shelf? What fraction of the sediment load is captured by deltas? Does coastal erosion supply a significant amount of sediment to the continental margins, unlike that found in the Beaufort Sea?

Based on the discussion above and evidence of successfully applying this new approach, I propose that the method be used on cores collected during the Russian continental margin study that is presently being planned. The method is fast and inexpensive, offering immediate estimates of carbon and sediment burial rates, while eliminating a variety of problems encountered by conventional geo-chronological methods.

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## FLUVIAL GEOCHEMISTRY OF THE RUSSIAN FAR EAST

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Very little information is available on the chemistry and sediment transport of the major rivers of the Arctic, particularly those draining Siberia. In total, the Arctic rivers represent at least 10% of the global runoff and drain a unique environment dominated by cryospheric interactions. They debouch into the polar ocean and strongly influence its density stratification and internal circulation. This influence is ultimately transmitted to the world ocean through the convective formation of dense deep waters in the Greenland-Norwegian Sea and their overflow into the North Atlantic. This process, crucial to the global heat transport budget, is thought to be extremely sensitive to the regional hydrologic balance. The oceanographic response of the Arctic to possible anthropogenic changes in global climate is therefore strongly amplified and could be crucial in determining the scale of the impact of an overall warming since the response would be highly non-linear, the cessation of production of the North Atlantic Deep Water. Prediction of the evolution of the anthropogenic transient in atmospheric CO<sub>2</sub> is compounded by the uncertainties in the estimates of the effects of warming on weathering reactions that consume CO<sub>2</sub> and their relation to associated changes in the hydrologic cycle. Comprehensive study of pristine boreal systems is required to constrain these effects in model simulations of Global Warming.

In the course of three summer field seasons (1991, 1992, 1994) we have made river transits of the Aldan, the major tributary of the Lena, from Yakutsk to Tammot, the head of navigation, the Kolyma from Simchan to Chersky at the head of the delta and the Upper Lena from Zhigalovo down to Yakutsk. On these transits all significant tributaries were sampled for the major and trace elements, suspended sediments and bed material. Additional "grab" samples have been collected from the Lower Lena by colleagues. The principal objective of this work is to establish the effects of cryospheric interactions on weathering processes and to compare these with existing information from Tropical environments, the Orinoco-Amazon system and the great rivers of China.

The major attraction of the rivers of the Russian Far East, as compared to the Yukon and Mackenzie in North America, is that the effects of glaciation is minimal, save in the Trans-Baikal Highlands and the Verkhoyansk Ranges. This allows the study of the weathering response of different lithologies in situ without the complication of an overburden of transported debris. The region is semi-arid; the annual precipitation is less than 500 mm and is dominated by summer rains. Thus accumulation of snow and ice is minimal. At present there are only a few small Alpine-type glaciers in the region. These expanded during the Last Glacial Maximum but did not develop into ice domes or penetrate to low elevations. The southern drainages are completely covered by Taiga forest save at the highest elevations (>~1500 meters). In the vast lowlands bordering the Arctic Ocean this forest cover gives way to tundra vegetation and, in summer, to numerous lakes and swamp tracts. Over most of the region the valley soils are

permanently frozen below depths of less than a meter. On the slopes gelifluction operates at all scales.

The rivers usually flow in deeply incised valleys that often display well preserved terraces. The headwater tributaries are gravel streams with both well rounded pebbles and also angular fragments up to boulder scale produced by the plucking action of bank-fast ice. The main-stems of the Lena and Kolyma are sand rivers. In the broad reach of the Lena beginning above Yakutsk large point bars are developed and tracts of wind-blown dunes envelop the forest on the river terraces.

The Upper Lena, north of Lake Baikal, is a prosperous dairy-farming region with large-scale production of fodder crops and potatoes. This activity diminishes steadily to the east and north along with the population density. Industrial activity is limited to mining of gold in the headwater regions and of diamonds, hard coal and placers in the interior. There is only one significant impoundment, the large hydropower dam on the Upper Vilyui, an important tributary of the Lower Lena. There is no evidence of significant environmental contamination or disruption in the rivers studied to date.

As compared to the Tropical rivers draining equivalent lithologies and topography the Siberian Rivers draining basement rocks have substantially higher dissolved loads; those draining the limestone terrains have similar concentrations to, for example, the Yangtze. There is no obvious effect of the much lower temperatures on weathering yields. Instead these are limited by the low runoff rates. The annual chemical fluxes from the basement rocks are thus comparable to those of the equivalent terrains in the Amazon-Orinoco. The relative compositions of the rivers are quite different, however. In the Tropics weathering is very intense such that the cation and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios are the same as those of the substrate being weathered. In the Lena-Kolyma weathering is very superficial. The rivers are generally clear streams with no suspended clays. The Sr isotopic ratios are quite non-radiogenic. It appears that in the Tropics the accumulation of a thick refractory mantle of severely weathered "laterite" acts to seal the system and strongly inhibit transport. Weathering at the subsurface "front" representing the unweathered substrate is intense but very slow. The effect of ice action is, by frost heave and gelifluction, to prevent the accumulation of a weathered mantle. Also, frost cracking produces fresh surfaces on a very large scale. The most labile constituents dissolve rapidly but the aluminosilicates seem to undergo only surficial ion exchange reactions with negligible clay formation. Thus the mechanical effects of the freeze-thaw cycle cancel out the inhibiting influence of low temperatures on the reaction rates. The weathering yields, expressed as the annual flux of dissolved cations, are the same in Tropical and boreal environments; the ionic compositions are quite different. The net areal consumption of atmospheric  $\text{CO}_2$  by weathering is essentially the same in the two environments.

Over the next few years it is hoped to extend this work to the Yana, Indigirka and other large rivers of the region. This work would not be possible without the generous provision of logistical support by the River Navigation Authority of the Russian Far East, based in Yakutsk, and the scientific collaboration of the hydrologists of the Laboratory for Erosion Studies in the Department of Geography of Moscow State University. The work at M.I.T. is supported by the Earth Surface Processes section of the N.S.F.

## QUATERNARY HISTORY OF NE SIBERIAN LOWLANDS/QUATERNARY BIOGEOGRAPHY OF THE MAGADAN OBLAST: CURRENT WORK AND KEY QUESTIONS

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The broad lowlands bordering the Arctic coast have never experienced major glaciation. Currently the region is strongly influenced by the Arctic Ocean, but for long periods of the Quaternary vast areas of shelf were subaerially exposed and conditions must have been much more continental. As much as several hundred meters of sediments have been deposited; usually less than 100 m are currently exposed. The uppermost deposits comprise the "yedoma". "Yedoma" describes a landscape eroded by thermokarst. It is also both the name applied to the frozen, silty sediments that make up most of the deposits and the name of the Late-Pleistocene formation that occupies most exposed sections. In certain localities, uplift has exposed older sediments. Studies at these sites, plus data from numerous deep wells, has allowed the elucidation of the late-Pliocene and Pleistocene stratigraphy and paleoenvironments. The record is considerably more complete and well-documented than that of the complementary regions of the northwest American Arctic. Chronology and correlation are based mainly on paleomagnetism and mammalian biostratigraphy. Further details are available in Kaplina et al. (1980), Sher (1974), Sher et al. (1979), Virina et al. (1984).

Several key questions concerning past environments and climates are closely tied to the origins and nature of the yedoma deposits themselves. Most deposition is assumed to have been during cold periods, including the LGM -- a period of extreme interest to both paleoecologists and paleoclimatologists. The process of deposition is still debated; there are two hypotheses, eolian and fluvio-lacustrine. Probably both wind and water have reworked the silts; even more fundamental is their initial source, given the large volumes of material and relatively restricted glaciated regions to the south. No conclusive data suggest a marine origin. The silts contain huge amounts of ice, both as fine lenses and massive ice wedges, which themselves have interesting and not completely explained paleoclimatic implications. Pollen, beetles, oribatid mites, vertebrate remains and other fossils are found in the yedoma. Interpretations are hindered by the uncertainty about depositional processes, but virtually all suggest an environment unlike modern mesic tundra. Most interpretations agree that the climate of full-glacial times was more arid and probably colder than present (Giterman et al. 1982). Curiously, although the last interglacial appears as peats, ice-wedge pseudomorphs, and lake sediments, interstadials are not readily identifiable in the yedoma. Does this indicate stability of climate through much of the Wisconsin (which would appear to be contrary to data from many other regions, except, perhaps eastern Beringia) or does it reflect intrinsic properties of the deposits themselves that somehow mask environmental change?

Berman (1990) has been studying possible modern analogues of the LGM (defined by indicator species) in the Magadan Oblast with respect to microclimate and vegetation. Other possible analogue communities, in Wrangel Island, along the northern coast, and in the arid continental interior of Yakutia are targets for further study. Local climatic conditions in restricted landscape patches that appear to be analogues can theoretically be scaled up to a landscape or regional scale using nested models. This approach takes the topographic mosaic into account when reconstructing past environments.

Erosion of the yedoma by thermokarst appears to take place mainly in warm periods. "Alas" or thaw lakes leave recognizable deposits, often with datable basal trash layers. Alas deposits corresponding to the early Holocene are common, and support the treeline data (see Anderson et al abstract) in suggesting a thermal maximum ca 9000 yr BP. The last interglacial and the early Holocene are both possible partial climatic analogues for future global warming. Melting of permafrost clearly has implications for both heat and carbon fluxes between land and atmosphere. Work in this area is currently being carried out by Gilichinsky and colleagues (Gilichinsky 1990, Gilichinsky et al. in press) and the subject deserves further study. Thermokarst is a major element of erosion in northern landscapes (hence the Yakutian term "yedoma"). Interglacial landscapes are literally transformed by it as much as they are by vegetation change. There is a strong Russian tradition of permafrost study that could be accessed in relation to these questions (for example, the work of Dr. Yuri Shur, UAF).

A summary of GCM simulations for Beringia, including northeast Siberia, has been written by Bartlein (in press). GCMs offer an independent climatic framework with which to compare environmental changes recorded in the geologic record. For example, it is possible that there were significant gradients in precipitation and effective moisture across Beringia, with northeast Siberia being moister in the LGM than corresponding parts of North America. Continued collaboration of geologists and paleoclimatologists would appear to be an essential element in both studies of Quaternary environments and attempts to validate GCMs.

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## ENVIRONMENTAL CHANGE IN NORTHEAST SIBERIA: A MULTIDISCIPLINARY APPROACH

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The field work portion of our project to study environmental history in Northeast Siberia has been successfully accomplished with close interval sampling from four key sites, in addition to sampling at secondary sites. Field activity was coordinated on a truly international scale, with participants representing six countries. Field work took place from July 25 to August 9, 1994. The data we collected will be analyzed for pollen, macrofossils, and physical and chemical characteristics. This data is first to be so intensively sampled and so comprehensively analyzed for paleoenvironmental information in the Yakutian region of Russia. This preliminary report outlines the accomplishments of the field work and plans for data analysis and reporting of our findings.

Several factors ensured the success of this field season. The first preceded the actual trip. Our original request for funding to National Geographic was designed as supplemental to a National Science Foundation grant. Despite excellent reviews, the proposal was declined on the basis of the controversial nature of the Yedoma sediments, very much based on similar arguments brought up by reviewers of the National Geographic proposal. Upon hearing that we had indeed received National Geographic funding, I requested Dr. Scott Borg, program manager at NSF Polar Programs, to reconsider funding a Small Grant for Exploratory Research (SGER) with a much smaller budget, but which will at least assure that our data can be analyzed. Our success in the field was aided by the expertise of our Russian colleagues. We were joined by two leading Russian soil scientists: Dr. Galina Mazhitova, of the Institute of Biological Problems of the North, Magadan and Dr. Stanislav Gubin, Institute of Soil Science and Photosynthesis, Pushchino, Moscow. Logistics were coordinated by Dr. Sergei Zimov, geographer and chief of the North-eastern Scientific Station, Pacific Institute of Geography, RAN, in Cherskiy. Our invitation was arranged by Dr. Daniel Bermann, also of the Institute of Biological Problems of the North, Magadan. Although Dr. Andrei Sher was not able to join us in the field, he will continue as a close collaborator in this project.

The other factor ensuring the achievement of our goals was excellent coordination, carried out by Dr. C. L. Ping, with the International Cryosol Working Group, who were engaged in determining the genesis and characterization of Arctic soils the group consisted of 14 American, Canadian, Chinese, Danish, and German scientists. Their participation gave us an opportunity to forge new alliances with other government agencies and universities, and to integrate new information on soils and cryopedology into the original project.

We made a decision to focus on the Kolyma lowlands, and exclude the Wrangel Island portion from our schedule. The decision was based on logistic and financial concerns, since the helicopter trip to Wrangel Island had become prohibitively expensive, and climatic and equipment concerns made scheduling very unpredictable. We also recognized that our scientific goals would be best achieved by focusing on the specific region and set of questions. We hope that this international effort will lead to further projects, but there is a trend toward increasing difficulties in the Russian transportation system, and the maintenance of a support network for



exploratory science in the Siberian Arctic is essential. This region has high research potential, but outside support is required.

### **1994 Accomplishments**

1. Two major sites were investigated: The Zeleniy Mys loess deposits in Chersky (Figure 1 and Figure 2; nr. 1), and the river bank exposures at Duvanny Yar (Figure 2; nr. 2). Both sites are located in the Yakutian region, along the lower Kolyma River. Zeleniy Mys was sampled both in the Yedoma, or ice-rich section, and the alas, or thermokarst depressions. Using portable drilling equipment, we were able to cut deeply into the permanently frozen soil, and have almost certainly procured material which encompasses the late Pleistocene, the Pleistocene/Holocene transition period--an important time period for understanding past and future climate change--and the entire Holocene. The alas samples were taken every 5 cm to a depth of 120 cm. In the Yedoma, samples were taken at 10 cm intervals to 225 cm. At Duvanny Yar, the same sampling strategy was used: sampling in both Yedoma and alas, with parallel samples taken for soil analysis, radiocarbon dating, and  $\delta^{13}\text{C}$  composition of plant material, to be undertaken by Dr. Eva Maria Pfeiffer, University of Hamburg. The Yedoma section was sampled every 10 cm to 248 cm, and the alas to 160 cm.

2. Several other sites were also sampled for comparative pollen deposition data. Dr. Yuri Shur, cryogeologist, and Adjunct Faculty at the Agricultural and Forestry Experiment Station, University of Alaska, and Dr. Ping were able to identify the cryogenic structures and active layer dynamics of the deposits, enabling us to identify sites and use sampling techniques which will ensure high quality analysis and interpretation. Some of this material shows evidence of grassland soil formation and frequent fire incidents during the late Ice Age, while other sections indicate massive thawing of the permafrost table during the early Holocene. Dating and soil analysis, will indicate changes in carbon accumulation, while paleoecological analysis, including analysis of  $\delta^{13}\text{C}$  composition, will indicate the vegetation changes.

3. Samples were taken from buried soil sections and pit samples at Duvanny Yar, primarily for correlative purposes, and at several soil sampling sites in the Rodinka Mountain Area. These sites were part of the USDA-SCS world soils database mapping project and included soil genesis, soil geography, and soil morphological description. Dr. Ping and Dr. John Kimble, USDA-SCS National Soil Survey Center, Lincoln, Nebraska, led the soil characterization sampling.

### ***Laboratory Analysis and Reporting***

The data - peat and lake samples from the exposed river banks and tundra regions of Northeast Siberia- are in remote regions, are not usually accessible to western scientists, and this was a one-time opportunity to visit them. Analysis of the samples has already begun.

Pollen analysis in complex depositional environments is controversial, but excellent results can be achieved by careful interpretation of sediments and the cooperation of stratigraphers and palynologists. Many palynologists are concerned about sampling complex sediments, but they do not realize the lack of suitable lakes in these regions makes these sediments the only source of paleoenvironmental information. Additionally, the pollen analysis of these deposits offers insights into their development, and the vegetation and climate regime at the time of formation. The reviewers of the National Geographic Society grant raised good points on how to achieve correct identification of complex sediment origins, and we plan to incorporate these suggestions

into our research. This requires the application of new approaches, and by linking research with the cooperating soil scientists, with backgrounds in cryopedology, soil geography, and organic chemistry, we believe that a comprehensive study of these deposits will be achieved.

The pollen analysis will be carried out in tandem with soil analysis. Pair-sampling and complementary analyses of soils and microfossils will form the basis of future research. The soil analysis and organic matter fractionation will be carried out by Dr. Chien-Lu Ping, who is supported by grants, including the USDA-SCS Global Change Initiative, NSF Flux study, and the USDA Hatch Project. Material collected during the 1992 field season from Molotkovsky Kamen, on the Maluy Anyuy River, Lower Kolyma, (Environment and climate in north-eastern Siberia during the Holocene/Pleistocene transition, grant # 4790-92) will serve as comparative data.

A meeting of the field participants will be held at the American Society of Agronomy - Soil Science Society of American meeting to be held in Seattle, Washington on November 18, 1994. Dr. Charles Tarnocai, in his letter to the Chersky field participants has suggested that one of three objective to be for the program of the Cryosol Working Group (CWG) be: To foster and carry out research relating to the effect of past and future global changes on permafrost-affected soils. This would involve work on various aspects of soil carbon, paleoecology (including pollen data), soil-climate-related studies, and other studies relating to cryogenic processes.

When we have completed our analyses, Drs. Chien-Lu Ping, Yuri Shur, Eva-Maria Pfeiffer and myself will present our first results at the Arctic Workshop to be held in Quebec in March, 1995. A final report will also be submitted to the National Geographic Society.

## POST-GLACIAL EMERGENCE AND DISTRIBUTION OF LATE WEICHSELIAN ICE SHEET LOADS IN THE NORTHRN BARENTS AND KARA SEAS, RUSSIA

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One of the largest uncertainties in ice-volume estimates for the late Quaternary is the areal and vertical extent of ice sheets over the Barents and Kara Seas and other shallow shelves bordering northern Eurasia. Glacial-maximum ice-sheet reconstructions range from nearly complete glacier coverage of northern Eurasia by a contiguous marine-based ice sheet (e.g. Grosswald, 1988) to individual ice sheets and ice caps centered on the Arctic archipelagos and advancing onto the adjacent shelf (e.g. Velichko et al., 1984). The discrepancy between reconstructions is equivalent to a global sea-level contribution of 5 to 10 m.

The discovery of a glacial dimicton in the Barents Sea and moraine banks on the Svalbard continental slope leaves little doubt that the Barents Sea was covered by an ice sheet during the late Weichselian (Solheim et al., 1990; Gataullin et al., 1993). This ice sheet supported outlet glaciers that filled fjords and sounds on Spitsbergen and terminated at the shelf edge (Lehman and Forman, 1992; Mangerud et al., 1992). The timing of deglaciation and glacial-isostatic compensation is well documented for Svalbard, the western sector of the Barents Sea ice sheet (Forman, 1990; Lehman and Forman, 1992; Mangerud et al., 1992). However, there is little chronologic control on marine and terrestrial glacial and deglacial features in the eastern Barents Sea, Kara Sea, and other areas of the Russian Arctic, confounding reconstructions of late Quaternary ice sheets in northern Eurasia. We present new postglacial relative sea-level records from Franz Josef Land and northern Novaya Zemlya (Fig. 1) that provide constraints on deglaciation, areas of maximum glacier loading, and potential global sea-level contribution from former ice sheets on continental shelves in the Russian Arctic.

Raised beaches are ubiquitous on forelands that border the Barents Sea and provide a high-fidelity record of the response of the lithosphere to glacial loading and unloading. The altitude of raised beaches was measured by a Leitz digital altimeter (precision of 1 m) with mean high tide as the datum (tidal range is <0.6 m). The rate and course of relative sea-level change is determined by the radiocarbon dating of shell, driftwood, or marine-mammal bones from raised beaches with known elevations.

Previous reconstructions of a large ice sheet over the Kara Sea are based partially on the identification on Novaya Zemlya of raised-beaches to heights of 100 to 150 meters above sea level (m asl) (Grønlie, 1924; Zagorskaya, 1959; Kovaleva, 1974). In contrast, we found a uniformly low postglacial marine limit of  $11 \pm 1$  m asl on northwestern Novaya Zemlya, between Nordenskiöld and Foreigner Bays (Fig. 1). The marine limit is isochronous on the northeast coast of Novaya Zemlya and rises to  $\sim 18 \pm 2$  m asl (Fig. 1), indicating a thickening ice sheet toward the Kara Sea. Similar low Holocene marine limits have been identified on Kolguev Island, southern Barents Sea (11 m asl; Komissarova, 1972) and on the northeastern

(4 to 5 m asl; Aller and Uhl, 1936) and the southeastern (10 m asl; Gataullin, 1988) Kara Sea coasts (Fig. 1). Marine records from the mouth of Nordenskiöld Bay indicate deglaciation of coastal areas prior to 10 ka. (L. Polyak and S. Forman, unpublished data). However, radiocarbon ages of driftwood and marine mammal bones found near the marine limit indicate a later transgression of the sea sometime between 5 and 6 ka reflecting the dominance of isostatic recovery, with stabilization of global sea level (Fairbanks, 1989). A 35 yr tide gauge record from Russian Harbor on the northwest coast of Novaya Zemlya (Fig. 1) indicates that land is currently emerging at  $\sim 2$  mm/yr (Emery and Aubrey, 1991; p. 114), similar to rates inferred from postglacial uplift.

We have identified higher raised beaches on Novaya Zemlya up to  $\sim 100$  m altitude, but they are covered by a discontinuous and thin glacial drift. Mollusks from raised-marine deposits beneath this drift and above the Holocene marine-limit yield radiocarbon ages of  $>28$  ka indicating that the higher beaches on Novaya Zemlya reflect substantial glacier loading from a pre-late Weichselian event(s).

Field studies on Franz Josef Land concentrated on the raised-beach forelands on Hooker and Scot Kelty Islands adjacent to the 500-m-deep British Channel. These forelands are covered by a regressional raised-beach sequence, emplaced into an inferred late Weichselian drift. One of the oldest ages for deglaciation in the northern Barents Sea of 10.3 ka was obtained on in situ shells near the marine limit on Hooker Island on western Franz Josef Land. Similar deglacial ages have been determined for Edgeøya, eastern Svalbard (Landvik et al., 1992). The elevation of the marine limit and the isobases of emergence increase toward the southwest with the highest marine limit of  $49 \pm 2$  m asl on Bell Island. A southwest tilt of strandlines on Franz Josef Land and an eastern strandline tilt on Svalbard (Forman, 1990) indicate a thickening ice sheet into the northern Barents Sea.

Hooker and Scot Kelty Islands are covered by an extensive raised-beach sequence, which provides a detailed record of relative sea-level changes after deglaciation. Initial emergence on Hooker Island from  $\sim 10.3$  ka. to 8.0 ka. is apparently modest ( $<8$  m) reflecting the rate of uplift just outpacing the rate of eustatic sea-level rise. A radiocarbon age of  $8340 \pm 100$  yr B.P. on in situ paired valves of the mollusk, *Mya truncata* from a nearby raised glacial-marine sediment indicates that outlet glaciers were at or behind their present margins by the early Holocene, evidence against remnant glacier loading, dampening emergence. A radiocarbon age of  $775 \pm 65$  yr B.P. on driftwood from a raised beach at 1 m asl in a protected bay on Hooker Island indicates that emergence is not complete, with an inferred present emergence rate of 1 to 2 mm/yr.

#### **Discussion: Implications for Glaciation of the Barents and Kara Seas**

The maximum western expansion of the Barents Sea ice sheet probably occurred late in the glacial cycle sometime between 20 and 13 ka (Forman, 1990; Mangerud et al., 1992), simultaneous with high relative sea level, and early incursion of North Atlantic surface waters that may have nourished glacier growth (Hebbeln et al., 1994). Marine and terrestrial records from the western margin of the Barents Sea ice sheet show initial retreat sometime between 12.5 and 13.5 ka with glaciers at or behind present margins before 9.5 ka (Forman, 1990; Svendsen et al., 1992; Lehman and Forman, 1992). Radiocarbon ages from forelands on Franz Josef Land indicate full deglaciation of interisland channels by or before 10.3 ka. Terrestrial



and shelf records from the Barents Sea area indicate a later deglaciation than inferred from a light  $\delta^{18}\text{O}$  isotopic interval between 16.0 and 13.0 ka in Arctic Ocean marine cores (Jones and Keigwin, 1988; Stein et al., 1994). This light isotopic signal may not necessarily reflect ice-sheet collapse but signal drainage of ice-marginal lakes on Siberia or increased discharge of the Ob, Yenisey and Lena Rivers.

The new relative sea-level data from Franz Josef Land and Novaya Zemlya show maximum emergence for the past 5 ka and earlier centered over the northern Barents Sea (Fig. 1). We infer from the regional isobase pattern that Franz Josef Land and Novaya Zemlya sustained a thinner glacier load than at the hypothesized center of the ice sheet over Kong Karls Land, Svalbard, where Holocene raised beaches have been identified to 110 m asl (Salvigsen, 1981). The pattern of postglacial emergence indicates that the Barents Sea ice sheet was the dominant load, and glacier coverage of Novaya Zemlya was comparatively diminutive. Varying directions of glacial striae on Svalbard (Ingolfsson et al., 1992) support the presence of an ice divide in the northern Barents Sea with ice funneled through fjords and sounds on Svalbard.

The disintegration of the marine-based Barents Sea ice sheet may be coincident with the rapid initial rise in global sea-level between 13.0 and 11.5 ka (Fairbanks, 1989) and not in response to maximum isostatic depression (Jones and Keigwin, 1988). The rise in global sea-level may have destabilized the ice sheet particularly in the deepest part of Barents Sea, the troughs bordering the Barents Sea and the interisland channels on Franz Josef Land. The recent identification of iceberg scourer traces at 300 to 600 m water depths on the Yermak Plateau (Vogt et al., 1994) support the presence of a thick (>1000 m) ice sheet in the northern Barents Sea during the late Weichselian. The iceberg scour traces imply an ice sheet decoupled from the sea bed as it entered water depths of >500 m in the troughs bordering the Arctic Ocean. Elevated summer insolation values (Berger and Loutre, 1991), particularly later in the deglaciation between 12.0 and 9.0 ka probably accelerated the demise of land-based outlet glaciers of the Barents Sea ice sheet (Svendsen and Mangerud, 1992).

The current low rates of land emergence (1 to 2 mm/yr) and the relatively low marine limits (10 to 50 m asl) on Franz Josef Land and Novaya Zemlya are similar to the Austrheim area in southwestern Norway, within 150 km of the margin of the Fennoscandinavian ice sheet (Emery and Aubrey, 1991; p. 86-87; Hafsten, 1983). The similarity in the present and post-glacial emergence rates between southwestern Norway and Franz Josef Land and Novaya Zemlya may reflect equivalent ice-sheet loads, assuming similar earth rheology and deglacial history. The reconstructed ice sheet thickness during the late Weichselian over southwestern Norway is ~1500 m (Tushingham and Peltier, 1991; Elverhøi et al., 1993), which is our initial estimate of the thickness of the Barents Sea ice sheet over Franz Josef Land and northern Novaya Zemlya. The Barents Sea ice sheet with an inferred maximum thickness of 2500 m over the northern Barents Sea and thinning to ~1500 m over Franz Josef Land and Novaya Zemlya, was a substantial sea-level reservoir during the last glaciation, accounting for ~6 m of global sea-level rise (Tushingham and Peltier, 1991).

The 1500 m estimated ice sheet thickness over Novaya Zemlya is, however, at least 40% thinner than previous estimates of 2500 to 3000 m (Grosswald, 1988; Tushingham and Peltier, 1991; Elverhøi et al., 1993), implying a thinner Kara Sea ice sheet. A 40% thinner ice sheet over Novaya Zemlya would reduce the global sea-level contribution from the Kara Sea

ice sheet to <4 m, less than a previous estimates of ~7 m (Tushingham and Peltier, 1991; Nakada and Lambeck, 1988).

The pattern of post-glacial emergence places the maximum ice-sheet load over the northern Barents Sea and thinning over Novaya Zemlya. Modest glacier thicknesses over northern Novaya Zemlya, further calls into question the presence of a thick (>1500 m) ice sheet over the Kara Sea that terminated on northern Siberia (Grosswald, 1988; Tushingham and Peltier, 1991). We contend that much of Siberia was distal to moisture sources, like northern Alaska, and thus, glacier extent possibly resembles limited valley-glacier and ice-cap expansion characteristic of the Brooks Range, Alaska (Hamilton, 1986). Many studies of the eastern Kara Sea (Astakhov, 1992), the Laptev Sea and adjacent lowlands. provide equivocal evidence for coverage by an large ice sheet but support the presence of a refugium with large Pleistocene mammals and possibly humans surviving throughout the late Weichselian into the Holocene (Makeyev et al., 1993).

This analysis of relative sea-level data from the northern Barents Sea potentially reduces the global sea-level contribution from ice sheets on Russian arctic continental shelves to between 6 and 10 m, considerably less than previous estimates of 16 m (Nakada and Lambeck, 1988; Tushingham and Peltier, 1991). The lower estimate on sea-level contribution from former ice sheets in the Russian Arctic increases the apparent discrepancy between eustatic sea-level depression and grounded global ice volume to over 30 m of global sea-level equivalent at the time of the last glacial maximum (cf. Andrews, 1992).

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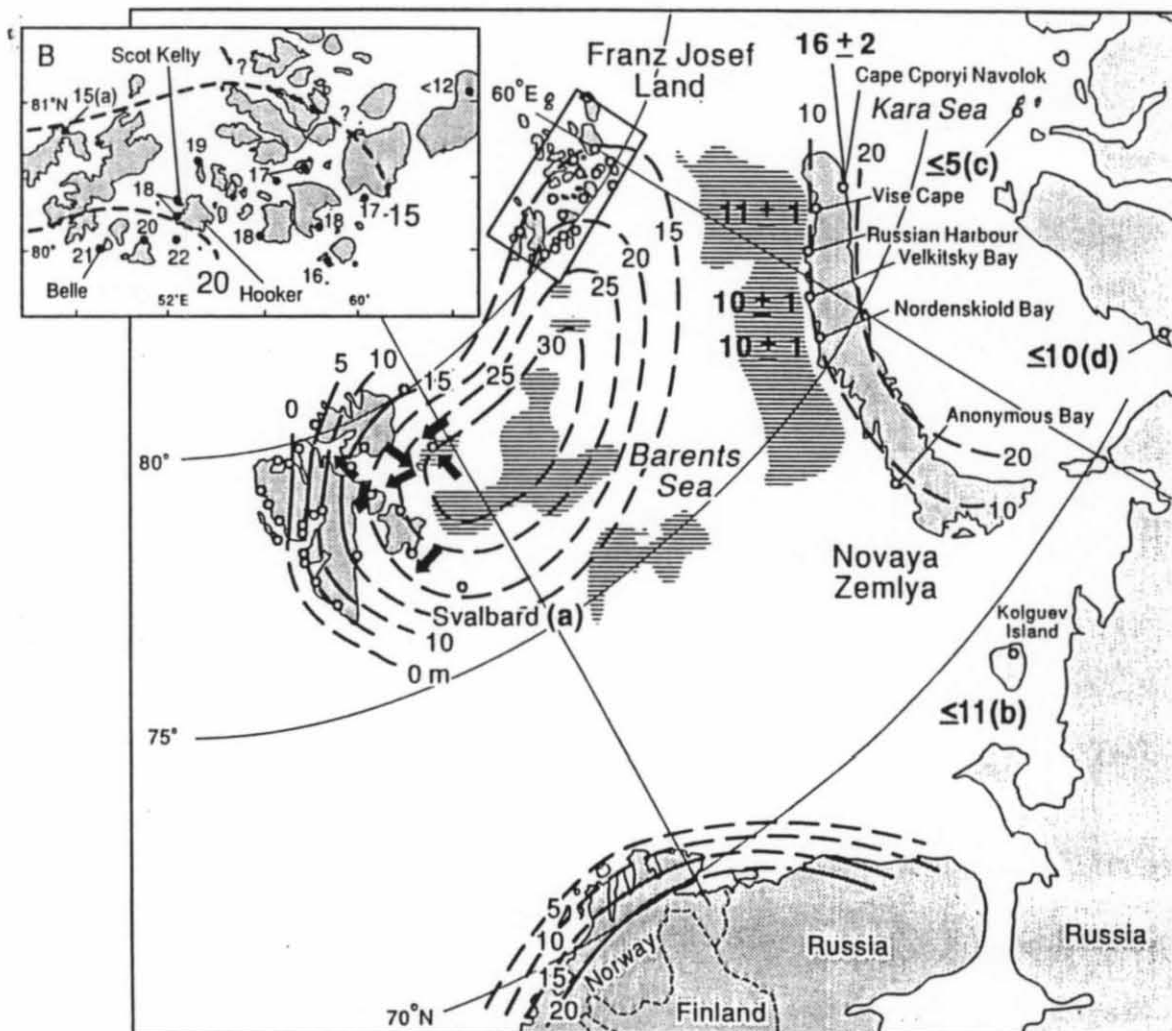
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**Figure 1.** Inferred isobases of emergence since 5 ka for Barents and Kara Seas. Isobase pattern for northern Fennoscandia from Møller (1987) and J. Snyder (1993 personal communic.). Data for Svalbard (a) from Forman (1990) and Møller et al. (1992). Altitude of Holocene marine limit on Kolguev Island (b; Komissarova 1972), Izvestia Islands (c: Aller and Uhl 1936) and Yamal Peninsula (d; Gataullin, 1988). Horizontally rulled pattern shows areas below 200 m water depth in northern Barents Sea. B: Inferred isobases of emergence since 5 ka for Franz Josef Land, Russia. Numbers indicate elevation of 5 ka old shoreline on islands of the archipelago. These observations are basis for constructing isobases.



# KARA SEA ICE SHEET - ITS EVIDENCE ON THE SOUTH-WESTERN KARA SEA SHELF AND ADJACENT MAINLAND

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## South-Western Kara Sea Coast

### *Existing Data*

The most impressive evidence the Kara Sea Ice Sheet left on the western coast of Yamal peninsula, where one can observe all stages of glacially affected transformation of stratified sediments into till - from glaciодislocated sediments through glaciотectonite and local till to final diamictic basal till. These facies first were distinguished by Dr. F. Kaplanskaya and V. Tarnogradskiy in 1979-80 near the polar station Marresale.

In 1982-86 the author carried out the continuous mapping of almost all cliff exposures on the coasts of Yamal and Yugorskiy peninsula by photographing the cliffs from the sea. The continuous photo mosaics (approximately 50 km) were prepared instantly in the field and were used as the base for plotting all geological data obtained from examination of the cliff exposures.

### *The Kara Till*

In the studied area the Kara Till is widespread occur to the south of the Tiuteljakha river. It can be subdivided into the lower unit: local basal till, constructed by intensively deformed underlying sediments and the upper unit: diamictic basal till enriched in foreign material consisting of bouldary loam or diamicton.

Both local and diamictic till are often found there in a frozen state and are comprised of up to 80% ice. The purposive examination of the glaciodynamic structures of this icy till with bodies of massive ice allow to consider that it is a primordially frozen till, which is a non-thawed, debris laden basal part of the glacier and which, due to incomplete deglaciation, preserved until now.

The Kara Till contains foraminifera and mollusk shells, and a rather small amount of clasts. Among them occur local Cretaceous and Paleocene silts and opokalike clays, as well as, Paleozoic Novaya Zemlya limestone, sandstones and shales. This indicates drift from the Kara Sea shelf and Novaya Zemlya and contradicts the Polar Ural Ice dispersal.

### *Glaciотectonics*

Kara Till exhibits explicit glaciodynamic structures and is accompanied by glaciодislocations in the underlying sediments. Glaciотectonics is developed more effectively in the vicinity of Marresale, where Upper Quaternary sediments are compressed into a large anticlinal structure with the amplitude of about 150 m and the wavelength of no less than 20 km.

Among the disturbances one can distinguish several groups, varying in their appearance, genesis and age. There are various fold, faults - mainly thrust faults, features of diapism overprinted on the folding strata, various glaciodynamic structures in the Kara Till, etc. Not going into the morphology and genesis of dislocations, it must be noted, that they have clear linear orientation, indicating a south-southwest stress direction.

Similar dislocations were observed also to the south of Marresale and on Yugorskiy Peninsula. In the strike of glaciodepression axes one can see the regular tendency. In general they reveal a shoelike disposition along the whole coast of the Baydaratskaya Guba, which can be considered as glaciodepression. Features of fold strike and overturning also indicate that the grounded Kara Sea Ice Sheet invaded the coasts of Yamal and Yugorskiy peninsula as a Baydaratskaya lobe from the Kara Sea shelf. Character of dislocations point out to their forming by actively moving ice.

#### *The Age of the Last Glaciation*

The age of the Kara Till is problematic. On the one hand, on the western coast of Yamal peninsula the Kara Till is underlain by fluvial sands with C14 datings of 26-42 kyr BP, obtained from redeposited, scattered wood fragments, and overlain by subaerial loess-like sandy silts with ice wedges, mammoth fauna and grass roots with available datings of 13-14 kyr BP. These datings indicate to the Late Weichselian age of the Kara Till. On the other hand, similar subaerial sediments from the eastern coast of Yamal peninsula have C14 datings of 22-30 kyr BP (Vasilchuk et al., 1984).

### **Southwestern Kara Sea Shelf**

#### *Existing Data*

The Kara and Barents Sea shelves form a common global paleogeographical region. In this connection comparison of these areas can provide the new outlook in settlement of principal questions of the Kara Sea Quaternary geology and paleogeography. Estimating the existing data from the Kara Sea shelf, it must be noted, that in comparison with data from the Barents Sea, which is one of the most studied shelf areas in the Russian Arctic, the factual base of the Kara Sea is much more scanty, and is insufficient for reliable paleogeographical reconstructions on so vast a territory.

In the south-eastern Barents Sea there are about 85,000 km of continuous shallow seismic, while in the south-western Kara Sea there are only about 10,000 km, with a resolution of 5-10 m.

In the Barents Sea there are about 300 boreholes, while in the Kara Sea there are only 20 boreholes, which are situated practically in 4 points.

Quaternary seismostratigraphy is complicated also by shallow depths of the major part of the Kara Sea and by the presence of permafrost.

#### *Relief*

In the south-eastern Barents Sea the bottom relief and Sub-Quaternary surface have explicit regularly-oriented linear character, which indicate the glacial movement from the Novaya Zemlya side to the western shelf break. In the south-western Kara Sea similar total display of ice movement traces is not observed. The only exception is the East Novaya Zemlya Trough, where strongly marked linear orientation of relief reflects the glacial movement along the Novaya Zemlya. The main part of the region, the West-Kara Plain, has chaotically oriented, intensively rugged hummocky relief with intricate, winding patterns of isobaths. The most important uncertainty is the existence of specific short and narrow incisions up to 100-200 m



depth.

#### *Glacial Deposits*

On the Barents Sea shelf glacial deposits with chaotic seismic signature occur everywhere, and in some places, especially west off Novaya Zemlya, they form a system of end-moraine ridges, which also demonstrate the glacial movement from the Novaya Zemlya side. On the contrary, on the Kara Sea shelf the till cover is very thin (5-10 cm) and in many places is practically absent. Here, end-moraine ridges occur only along the western and particularly the eastern slopes of the Novaya Zemlya Trough, where till reaches a thickness of 50 m.

#### *Postglacial Sediments*

Typical basin sediments with stratified seismic signature (Late Weichselian glaciolacustrine-glaciomarine and Holocene marine sediments) are widespread occur only in Yugorskiy depression, where their thickness reaches 100 m. On the rest part of the region they occur only in a small depressions and paleoincisions.

In all boreholes from the north-eastern part of studied area the Quaternary sequence also consist of undisturbed rhythmically banded sediments, but they are rather stiff and often occur in a frozen state (in many borings there are pieces of clear, probably vein ice). In these cases their stratified seismic signature disappears. These sediments are, probably, postglacial sediments, connected with the Early Weichselian (?) glaciation.

#### *Datings*

In the south-western Kara Sea there is now only one AMS radiocarbon dating (9740 yr BP) from the base of marine sediments, which is the same as numerous datings in the Barents Sea. These datings show that the final deglaciation both in the Barents and Kara shelf took place approximately 9.5 kyr BP.

In conclusion, it must be noted that there are a few alternative models of the Kara Sea Ice Sheet, proposed by Velichko, Grosswald, Astakhov, Pavlidis and others, but they are poorly confirmed by geological data, particularly from the shelf areas. For reliable paleogeographical reconstructions we need to interpret all shallow seismic, obtained by various Russian institutions and to construct the reliable bathymetric map and contour thickness maps for each seismic unit as well as to receive reliable datings.



# THE RECORD OF HUMAN OCCUPATION OF THE RUSSIAN SUBARCTIC AND ARCTIC

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## Introduction

To date, only one Paleolithic archaeological site has been discovered in the Russian Arctic: the famous Berelekh site located in northeastern Yakutia; however, when we expand our search to include the Russian subarctic (55-65° N latitude), that number rises to nearly 50. The archaeology of subarctic Russia promises to provide insights into two issues that have long fascinated anthropologists: the evolution of northern hunter-gatherer adaptations and the peopling of the Americas.

Below I examine the archaeological record of the Russian north from the first archaeological traces through to the mid-Holocene. I then review some primary research objectives driving Russian subarctic and arctic archaeology today, and some important research questions that will likely guide future archaeological research in the area.

## The Record of Human Habitation in the Russian Arctic and Subarctic

### *Lower Paleolithic (>130 thousand years ago [kya]).*

The existence of a Lower Paleolithic occupation in the Russian arctic and subarctic is ambiguous. A handful of sites have been discovered, but only one has been extensively researched, Diring Iuriakh. Proposed absolute ages for Diring range from 2.5-1.5 million years ago (mya) (Mochanov, 1988) to 300-200 kya (Ranov and Tseitlin, 1991). To some archaeologists, however, the dating of Diring is a non-issue, since many of the excavated artifacts appear to be the result of natural processes, not hominid activity (Mochanov, 1988). Another purported Lower Paleolithic site recently found in the Russian north is Kymyneikei, located near Koluchinskaia Bay along the north coast of Chukotka (Laukhin et al., 1989). Reported Paleolithic artifacts include six flakes and a "wedge-shaped artifact," which to me appear to be nothing more than naturally fractured cobbles with sharp edges.

### *Middle Paleolithic (130-40 kya)*

In the last ten years our knowledge of the Siberian Middle Paleolithic has increased dramatically. Recent work in southwest Siberia (the Altai and upper Yenisei basin, 50-55° N latitude) has revealed the presence of a group of Middle Paleolithic (Mousterian) sites dating from the Last Interglacial through to around 40 kya (Abramova, 1985; Derevianko and Markin, 1990; Derevianko et al., 1990, 1992). Associated but fragmentary hominid fossil remains from two of these sites, Denisova Peshchera and Peshchera Okladnikova, suggest that the makers of these industries were Neanderthals (Turner, 1990). In the Russian arctic or subarctic, however, Middle Paleolithic or Mousterian sites have not yet been discovered.

### *Early Upper Paleolithic (40-20 kya)*

Initial Upper Paleolithic industries appear by 40 kya throughout south Siberia (Goebel, in press; Goebel and Aksenov n.d.). The Middle to Upper Paleolithic transition was widespread,

and at some sites (i.e., Kara-Bom) the transition to blade technologies was sudden (Goebel et al., 1993). Some archaeologists have hypothesized that this event marks the migration of anatomically modern humans into Siberia from southwest Asia and the extinction of local Neanderthal populations (Goebel, 1993). After 30 kya, the first unequivocal Paleolithic sites appear in subarctic Russia (55-65° N latitude). Presently, four groups of sites can be identified. West of the Ural Mountains in northern European Russia, Sungir', Byzovaia and a few other early Upper Paleolithic sites document the spread of humans as far as 64° N by 25 kya (Bader, 1978; Kanivets, 1976). East of the Urals in the West Siberian Plain several early Upper Paleolithic sites (i.e., Mogochino-1, Tomsk, Achinsk) dating to between 25 and 18 kya have been found at latitudes of 55-57° N (Petrin, 1986; Larichev et al., 1988). A third cluster of sites has recently come to light in subarctic east Siberia along the upper Lena, Nizhnaia Tunguska and Angara Rivers at latitudes reaching 60° N. Initial radiocarbon dates from Shishkino-8, Alekseevsk, Nepa-1 and Ust'-Kova range from 26 kya to 21 kya (Perzhakov, 1987; SEBmin, 1987; SEBmin and Shelkovaia, 1991; Zdonin et al., 1991). The fourth group, finally, is the "Proto-Diuktai" complex of the Aldan basin, Yakutia. Two sites, Ust'-Mil'-2 and Ikhine-2, have been radiocarbon dated to between 35 and 24 kya (Mochanov, 1977), but associations of radiocarbon dated materials and artifacts have been questioned (Hopkins et al., 1982; Yi and Clark, 1985). Nonetheless, these four groups of sites, covering the Russian subarctic from the Pechora to the Lena River basins, suggest that the earliest sustained hominid occupation of the Russian subarctic occurred 30-20 kya, just prior to the last glacial maximum.

#### *Late Upper Paleolithic (20-10 kya).*

After the last glacial maximum, wedge-shaped core and microblade industries (i.e., the Diuktai, Kokorevo, and Afontova complexes) with slotted antler points, burins, and lanceolate bifaces emerged for the first time in the Siberian subarctic and arctic. The point of origin of these industries is unknown at present; however, some of the earliest dated wedge-shaped core sites have been found in the Lena River basin of Yakutia (i.e., Verkhne-Troitskaia and Makarovo-6, both dated to c. 18 kya) (Mochanov, 1977; M. Aksenov, pers. comm.). By 14 kya, this late Upper Paleolithic complex had spread throughout southern Siberia and Yakutia. In Beringia east of the Verkhoyansk Mountains, however, microblade technologies appear rather late in time, after 11 kya (Hoffecker et al., 1993). Beringian sites predating 11 kya (Ushki layer 7, Berelekh, Nenana complex in Alaska) have been labeled "premicroblade" because they are characterized not by microblade technologies, but by blade and flake technologies and tool assemblages with scrapers, knives, graters, and small triangular or teardrop-shaped bifacial points (Goebel et al., 1991). It has been hypothesized that the premicroblade and microblade complexes represent two separate human migrations into Beringia during the late Upper Pleistocene.

#### *Mesolithic-Early Neolithic (10-5 kya).*

At the end of the Pleistocene, climatic warming encouraged prolonged human settlement in the Russian arctic and even high arctic. Mesolithic complexes dating to 10-7 kya have been identified in the Kola Peninsula, Pechora basin, North Siberian Lowland, Taimyr Peninsula, arctic Yakutia and Chukotka (Shumkin, 1973; Stokoloc and Korolev, 1984; Khlobystin, 1982; Argunov, 1990; Mochanov, 1977; Dikov, 1979). Furthermore, a new Mesolithic site located on the New Siberian island of Zhokhova (75° latitude) has been radiocarbon dated to 8-7 kya (Pitul'ko et al., 1990). Associated faunal remains (365 examples) include reindeer (50.2%),

polar bear (44.6%) and isolated specimens of pinniped, wolf and bird. If future research on Zhokhova Island confirms these initial discoveries, this site represents a more extensive Mesolithic settlement of the Russian north than previously thought.

From 6 to 4 kya, early Neolithic cultures (i.e., the Syalakh and Bel'kachi of Yakutia) with ceramic and ground/polished stone tool technologies replace Mesolithic cultures across the Russian arctic, from the Kola Peninsula to Chukotka. Early Neolithic sites are typically located along rivers, on inland lakes and sometimes on high mountain passes, but not along the Arctic coast. The earliest documented maritime cultures in the Russian north appear between 3 and 2 kya along the Sea of Okhotsk, Bering Sea, North Chukotka and Wrangell Island coasts (Lebedintsev, 1990; Vasil'evskii, 1971; Dikov, 1979; Tein, 1979).

### **Major Research Goals**

Our knowledge of the archaeological record of the Russian arctic and subarctic has grown significantly since 1980, as the above review indicates. Nonetheless, the extraordinarily low density of dated sites over such a vast area makes today's archaeological research agenda unavoidably elementary. Five major goals are outlined below.

**Goal 1.** Establishing complete and precise Upper Pleistocene and Holocene geochronologic and paleoclimatic sequences. Accurate geological, palynological, and paleogeographical frameworks are critical to understanding the archaeological record of northern Russia. Presently, nearly all regional stratigraphic correlations are based on faulty radiocarbon chronologies or tentative relative chronologies, and virtually all paleoenvironmental reconstructions are based on pollen records from alluvial contexts. Geologic sections need to be redated with state of the art absolute techniques like accelerator radiocarbon and luminescence procedures; palynological records need to be recovered from lacustrine systems.

**Goal 2.** Dating Paleolithic, Mesolithic, and Neolithic sites and placing them in chronological frameworks. In the past, archaeological sites in Siberia and the Russian Far Northeast have been dated only through conventional radiocarbon methods or through tentative typological or stratigraphic comparisons. In the last five years, however, several research projects have been directed at this issue; M. Waters has been investigating chronological aspects of Diring Iuriakh, and T. Goebel has been involved in campaigns to redate the south Siberian early Upper Paleolithic and the Upper Kolyma Mesolithic and Neolithic records. Additional dating programs like these need to be accomplished so that all of the archaeological complexes of subarctic and arctic Russia can be put into secure chronological frameworks. Accelerator radiocarbon, electronspin resonance, and luminescence (i.e., thermoluminescence, infra-redstimulated luminescence, optically stimulated luminescence) procedures need to be used to date entire profiles of stratified sites, not just cultural components.

**Goal 3.** Defining past human technologies, lifeways, and cultures. Although numerous archaeological sites and complexes have been identified in northern Russia, only recently have we begun to try to use these data to reconstruct the evolution of northern hunter-gatherer adaptations. Although for years analyses of artifacts have been solely descriptive and typological, today a handful of lithic specialists are beginning to focus on explaining why typological as well as technological variability exists in the Siberian archaeological record. Furthermore, faunal assemblages from northern archaeological sites have never been studied beyond initial species identification, and rigorous zooarchaeological and taphonomic analyses are only now being proposed. For this reason, even after nearly 100 years of northern Russian archaeology, we

know next to nothing about Paleolithic, Mesolithic, or Neolithic lifeways in the region.

**Goal 4.** Improving excavation techniques and materials. Rarely do excavations in the Russian north follow the rigorous guidelines set by American and European archaeologists. Excavations are often ill-equipped; simple items like tape-measures and surveying instruments are in short supply. Materials as well as instruction in advanced excavation procedures need to be available to Russian colleagues, perhaps through formal international exchanges so that Russian archaeologists can participate in American excavations and field research programs.

**Goal 5.** Improving infrastructure for communication. Presently it is difficult and often impossible for us in the U.S. to communicate with colleagues in the "wilds" of Siberia. E-mail stations need to be set up at Russian institutes and universities to facilitate better communication internationally. In addition, annual workshops held in the U.S. or Russia (such as this one) will quickly lead to stronger research ties and collegiality between American and Russian scientists.

### Major Research Questions

Below is a list of some major research questions that will likely direct future archaeological research in the Russian subarctic and arctic. This list is neither complete nor prioritized.

1. When was the Russian subarctic (55-65°) originally colonized?
2. What is the evidence for a pre-modern human occupation of Siberia?
3. When did anatomically modern humans emerge in the Russian subarctic?
4. During the Paleolithic, when, where, and how did human adaptations to northern living evolve?
5. How did pre-modern and modern human populations in subarctic/arctic Russia respond to downturns in climate during the Upper Pleistocene?
6. Where, when, and how did early Upper Paleolithic blade technologies/cultures emerge in Siberia?
7. Where, when, and how did late Upper Paleolithic microblade technologies/cultures emerge in northeast Asia?
8. Was Siberia occupied by humans during the last glacial maximum (22-18 kya)?
9. When was Beringia first colonized by humans?
10. Is subarctic Siberia the ancestral "homeland" of Native American populations?
11. Were there three founding migrations of New World populations from northeast Asia into the Americas? When did these migrations occur?
12. How did late Upper Paleolithic humans in the Russian subarctic and arctic respond to climate changes across the Pleistocene-Holocene boundary?
13. When and how did humans colonize the Russian arctic (65-75° N) and high arctic (>75°)?
14. How extensive was the Sumnagin Mesolithic occupation of the Russian arctic and subarctic?
15. When, where, and how did northern maritime adaptations emerge?
16. When, where, and how did northern herding adaptations emerge?

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## BIOGEOCHEMICAL CARBON CYCLING AND ECOSYSTEM DYNAMICS IN ARCTIC MARINE AND TERRESTRIAL SYSTEM

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Our research program involves studies of sources, sinks and transformations of carbon and nitrogen that have occurred in both marine and terrestrial ecosystems of the Alaskan and Russian Arctic. We have been working on this topic for about ten years. The marine component has focused on biogeochemical cycling and ecosystem dynamics in the Bering and Chukchi Seas as well as the Arctic basin. Topics of interest include pelagic-benthic coupling, benthic carbon cycling, benthic population structure, and the use of stable oxygen isotope ratios and nutrient content to follow contributions of Pacific Ocean water, brine injection, and freshwater transport in relation to formation of the Arctic Ocean halocline and nutrient maximum. We have also been using a combination of natural and anthropogenic radioisotopes to trace organic carbon and sediment deposition and accumulation, and mechanisms for transport of materials from the shelf to deep basin regions of the Arctic (e.g. Grebmeier et al., 1990; Grebmeier and Barry, 1991; Grebmeier, 1993, Cooper et al. 1994b, Grebmeier and Cooper, 1995). The terrestrial studies have investigated hydrological processes in Alaskan tundra and sedimentation in lake sediments (Cooper et al. 1991, 1993, 1994 a, b).

Currently, we are using biogeochemical techniques to study the ecosystem influenced by the St. Lawrence Island polynya (SLIP), an open-water area in the seasonally ice-covered region south of St. Lawrence Island in the northern Bering Sea, and its relationship to biological productivity and benthic carbon cycling in the region. We are particularly interested in the physical-biogeochemical relationship between the SLIP and the Gulf of Anadyr cold pool in sequestering and recycling organic carbon in this extremely productive northern region. We also have an ongoing project studying radiogenic contamination in marine waters, particularly near Alaska, and have a cruise planned to study contaminants and ecosystem health influenced by the Kolyma River discharge into the East Siberian and Chukchi Seas in 1995.

Important global change issues on the shelf zones of both the Russian and North American Arctic include the transport and sequestering of carbon from the productive surface layers of the ocean to both the continental shelf and the deep Arctic basin. Will the biological pump and its associated influence on the global carbon cycle be impacted with projected climate change? Will changes in sea ice cover occur and will the feedback increase or decrease oceanic current transport and water column production? Currently the shallow shelves of the Bering and Chukchi Sea are highly productive waters containing large benthic amphipod and bivalve communities that support large marine mammals, which are in turn important for local subsistence hunters. Transport conditions through Bering Strait influence the water type and nutrient content entering the Arctic halocline. Changes in physical forcing functions in the Arctic Ocean and marginal seas may dramatically influence biogeochemical cycling on the shelves and ecosystem function in general. Other questions can be linked to terrestrial processes. For example, if carbon losses from tundra increase with greater warming, will this carbon be deposited in the nearshore regions and, via microbial breakdown, enter the high Arctic shelf

regions that are currently nutrient-limited? What impact will these changes have throughout the ecosystem? The transport of contaminants from rivers into the sea has also of course become a major issue in the Arctic, especially in Russian waters where industrial development has progressed to the greatest extent of any Arctic nation.

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## THE ROLE OF HYDROLOGY IN ARCTIC ATMOSPHERIC AND OCEANIC PROCESSES

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Water and the hydrologic cycle permeates all of the physical, chemical and biologic structures of the earth system (Webster, 1994) regardless of geographic position. The earth is unique among planets because of the large quantity of water and the fact that the earth's environment is at a range of temperatures that allows water to exist in the vapor, liquid and solid phases. Physically this is important because of the moderating influence water has on our climate by virtue of the amounts of heat involved in phase change. Phase change of water can take many forms: freezing and thawing, condensation and evaporation, and sublimation and deposition. These processes can take place in the atmosphere, oceans, lakes and streams, lithosphere and biological system. Water is also an excellent conveyer of heat because of its high specific heat capacity and plays an important role in the transfer of heat from those areas of earth that have a positive influx of energy to those parts of earth with a negative efflux of energy. Both the oceans and the atmosphere partake in transporting excess energy from near-equatorial areas towards the poles.

Arctic areas (polar regions) play an important part in our climate by transferring excess energy back into space. The efficiency of this process depends on many hydrologic and meteorologic factors. Snow and ice cover are important candidates because of their high albedo relative to surfaces in warmer climates. Obviously the duration of snow and ice is important when looking at annual energy balances. A reduction in sea ice cover and snow cover would dramatically influence surface energy balances. Other candidates might be the low rates evaporation, transpiration and sublimation that return moisture to the atmosphere. These rates are limited by the low moisture capacity of the relatively cold atmospheres around the poles. Vapor pressures in polar regions are an order of magnitude less than tropical areas because of the large dependence on temperature. Lower moisture levels result in the development of high pressure systems that enhance long wave radiation cooling.

In the northern hemisphere, the polar region is dominated by the Arctic Ocean. This ocean is unique in that it is ice covered for much of the year and as oceans go, it is relatively shallow. Aagaard and Carmack (1989) discuss how the salinity stratification of this high-latitude ocean is critical to the vertical circulation. They also discuss two other hydrologic processes that are important in this region; freezing of ocean water and dilution by fresh water streams and rivers discharging into this ocean and associated seas. They compare the process of distillation by freezing to the process of evaporation in warmer climates, both result in the rejection of salt. It should be noted that this process is reversed when the ice melts, however this may be in a different locality as the ice migrates. Considerable ice leaves the Arctic basin through the seas east of Greenland.

The Arctic Ocean is the recipient of considerable fresh water from terrestrial areas. Rivers discharging into this ocean and associated seas range from extremely large rivers with drainages extending as far south as 50° N latitude to relatively small drainages from watersheds with continuous permafrost. The role of fresh water is important climatically as well as influencing ocean circulation. Aagaard and Carmack (1989) state that the introduction of small amounts of

fresh water can prevent convective overturn, even with substantial surface cooling. The residence time for water worldwide in the hydrologic cycle varies from > 3000 years for the oceans to < 2 weeks for the atmosphere. The residence time for glaciers (about 6000 years) is heavily biased by Antarctica and Greenland and the residence time for surface and subsurface flow is quite variable ranging from 2 weeks to 5 years and 2 weeks to 10,000 years respectively.

Considerable variation in streamflows occur during the year; with winter time precipitation coming as snow, orders of magnitude change are possible from peak summer flows to late winter flows. Webster (1994) reports a fortyfold increase in flow from late winter conditions on the Lena and Yenisei Rivers of Russia. While those rivers draining areas of continuous permafrost such as the Kuparuk River in Alaska could undergo as much as four orders of magnitude change. Accumulative plot of discharge (Figure 1) on log scale illustrates the range of flows encountered in the arctic basin for various sized rivers. However, the four largest rivers in the Arctic (Ob, Yenisei, Lena and MacKenzie) contribute 60 % of the total flow. The impact of climate change on the hydrology and climate of the Arctic has been reported in numerous papers (Hinzman and Kane, 1992; Roots, 1989; and Woo, 1990).

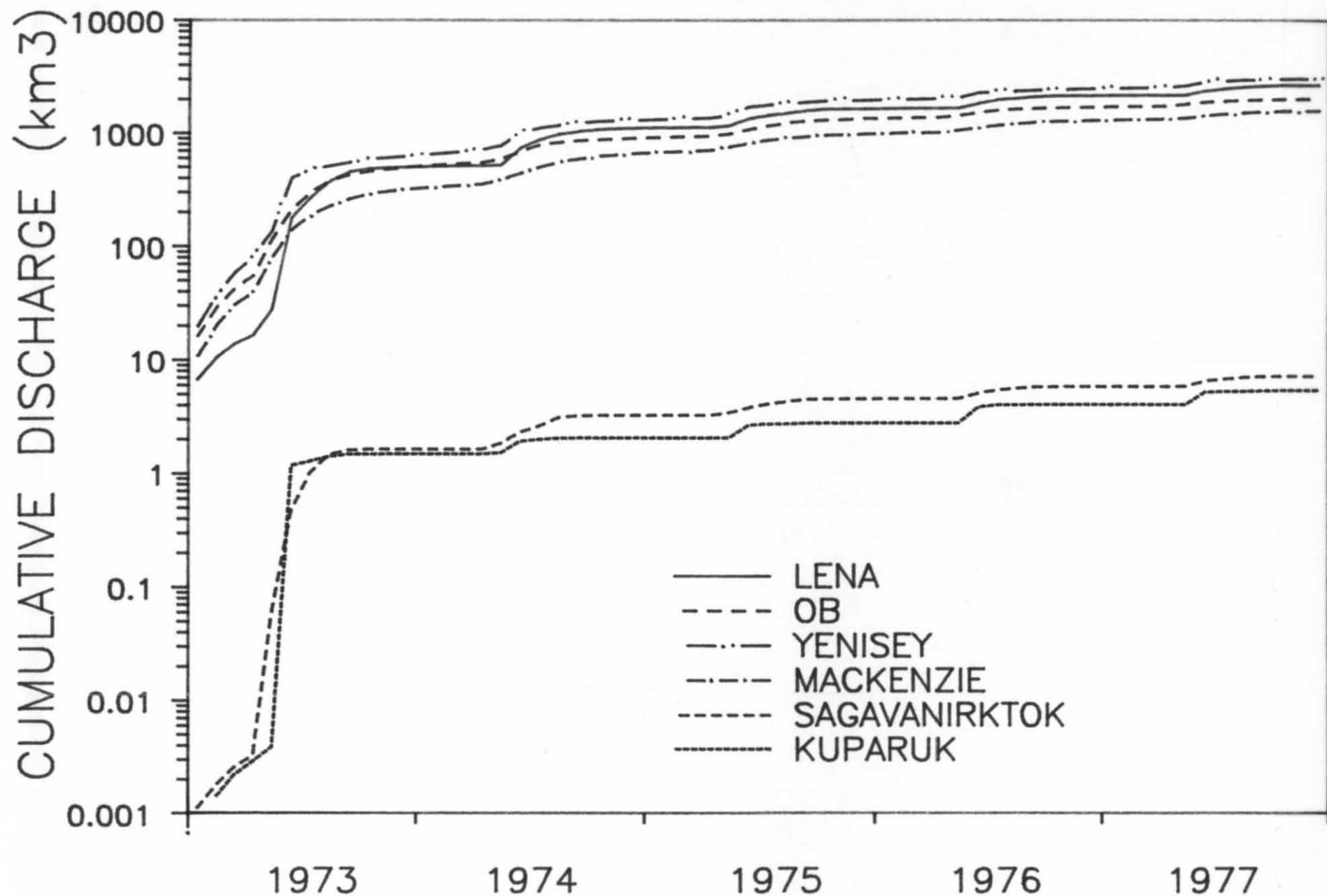
Predictions of the magnitude of climate change and the impact on the hydrologic processes is based on numerous assumptions and data of questionable quality. Overall, hydrologic data and our understanding of processes are both very poor. Data on energy and mass fluxes is meager, sometimes not continuous, not collected in the optimum areas (but logistically the most convenient) and often collected with instrumentation that fails to accurately measure the variable of interest. Spatially distributed data would be the most useful for global and mesoscale hydrologic models, data of this type does not exist at northern latitudes. Remotely sensed data from satellites is the only way to achieve this goal.

We have a long way to go before we have a worthy understanding of the basic hydrologic processes on the scale of the Arctic. However, the Arctic and the Antarctic play very important roles in the global engine that we call earth's climate.

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# CUMULATIVE DISCHARGE FOR SEVERAL ARCTIC RIVERS





## MEASURING THE FLUX OF MATERIALS FROM THE LAND TO THE SHELF

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### Research in the Russian Arctic

One circumarctic research question is the extent of release of terrestrially-derived CO<sub>2</sub> from streams and lakes. If there is an appreciable area of surface water then this pathway of CO<sub>2</sub> release to the atmosphere can constitute a significant amount of soil respiration missed by chamber and even tower measurements. The supersaturation of streams and lakes with CO<sub>2</sub> has been so far found by Kling et al. (1991) on the North Slope of Alaska (Kuparuk River area) and in the MacKenzie Delta area.

We have made preliminary measurements of trace gas exchange between surface waters and the atmosphere in Western Siberia, near the Pur River (Kling, in press). These data indicate that the strong supersaturation of surface waters and the resulting flux of CO<sub>2</sub> and CH<sub>4</sub> to the atmosphere may be a general condition for arctic tundra worldwide.

### NAS Young Investigator Program in Arctic Ecology

One of us (GK) has also been involved in the National Academy of Sciences Young Investigator Program in Arctic Ecology. The program was coordinated with the Russian National Academy, and provided reciprocal visits of 10 U.S. and 10 Russian scientists in 1993 and 1994. The purpose was to identify the scientific, environmental, and development concerns of the Arctic and far northern regions of the U.S. and Russia, and to establish contacts with Russian scientists and develop common research interests and collaborations. A common theme developed during the program and was focused on the question of "how will human impact change the Arctic". There are two fundamental requirements for answering this question. First, because most of the Arctic is contained within North America and Russia, any attempt to characterize and solve environmental issues in the Arctic requires a strong U.S.-Russian collaboration. Second, the Arctic represents a major biome and plays a critical role in our interacting biosphere. Understanding this role and the complex factors that affect it requires multidisciplinary research. For example, we must investigate how arctic ecosystems interact with the earth system through the land-water-atmosphere exchanges of materials such as pollutants and trace gases. We must also investigate how human activities and disturbance affect plant and animal communities, and how that may influence this exchange of materials. Finally, we must recognize the economical, political, and social forces that result in environmental change, and understand how this change feeds back through environmental concerns that result in policy and management decisions.

A preliminary report produced by the NAS arctic group is available, and discusses research opportunities and directions in the general areas of (1) vegetation and ecological mapping, (2) environmental physiology and toxicology, (3) pollution, (4) biogeochemical cycles, (5) natural resource economics and management, and (6) scientific education and outreach. Several specific research collaborations in these areas have been developed or strengthened. With this group of scientists we have a unique opportunity for addressing large-scale, complex environmental problems of the Arctic in a multidisciplinary effort. We can now examine a broader geographical representation of the Arctic, and we can merge the best elements of the approaches

that each scientific community has taken toward solving arctic environmental problems. For a variety of reasons, Russian research has traditionally concentrated on applied questions, and through mostly descriptive work has produced remarkable, often long-term, data sets on environmental characteristics of the north. In contrast, U.S. research has tended to be more experimental and process oriented, but often more restrictive in scope. The results from this approach have been used to develop mechanistic models of population, community, and ecosystem structure and function, as well as models of natural resource management and nonmarket valuation. We are now at the stage in our science where we need to test these models and their predictions against the long-term data and unique information that is only available from our Russian colleagues.

Our program also evaluated some of the problems involved in U.S.-Russian collaborative research. The most noticeable and pervasive is the difficulty of communication and coordination among researchers. Any program will fail without a substantial increase in the efficiency and reliability of communication between scientists in the U.S. and Russia, especially through FAX and EMAIL modes. A second problem is the general lack of coordination between research institutes in Russia. This may be due to many factors including the disciplinary way in which Russian science has been conducted, their political structure within the Academy and between the Academy and Universities, and the system of distributing research funds; perhaps eventual implementation of a western-style grant system for Russian research, especially with respect to facilitating cooperation among institutes, is needed to overcome this problem.

Measuring the Flux of Materials to the Arctic Ocean: Current Projects in Alaska. Several projects in northern Alaska are now measuring the flux of water, nutrients, and organic matter to the Arctic Ocean. The LTER project based at Toolik Lake has data on fluxes from the upper Kuparuk River for more than 15 years. The Flux Study (ARCSS) of Hobbie is cooperating with the LTER project and extending the measures to include the movement of CO<sub>2</sub> and CH<sub>4</sub> from land to atmosphere via water in soils, streams, and lakes. The Flux Study project is also measuring concentrations of materials in stream waters of the Kuparuk River and its tributaries in a series of transects along the entire river. Finally, the Flux Study project of Doug Kane is measuring water flow and nutrient concentrations in the upper Kuparuk River.

The goal of the LTER project over the next 3-5 years is not only to measure the fluxes of water and materials into the rivers and ocean but also to create process based models that will estimate the movement of materials from the land into streams in arctic tundras of various vegetation types. The major missing part of the research picture is water flow models. Doug Kane's model may be useful but it may well be at the wrong scale. The advice of a number of hydrologists is to apply TOPMODEL (Bevin and Wood, 1983) to the Kuparuk basin as it calculates not only the stream hydrograph but also information that is useful for linking hydrological calculations to hydrochemical models (Hornberger et al., 1994). TOPMODEL uses a topographic index calculated from digital elevation models as well as evapotranspiration, snowmelt, and channel routing. If resources can be gathered to implement TOPMODEL with the help of a postdoctoral scientist, it would be tested on the entire Kuparuk River basin using information developed from LTER and ARCSS projects. Special emphasis will be given to developing information, that can be used by the model, through remote sensing.

A second type of model that needs to be developed deals with the processing and changing of the

nutrients and organic matter once they enter the streams. Again, there are extensive data sets available for the upper Kuparuk system through the LTER research. ARCSS-funding to Hobbie and Kane is extending the data set to the entire basin. Some modeling of the nitrogen cycle has already been carried out by Peterson but the model needs to be extended to include explicit processes. At the present time, there are no process-based models being developed.

Measuring the Flux of Materials to the Arctic Ocean: Testing Models in the Russian Arctic. The real question for research is the flux of material from rivers to the entire Arctic Ocean and the flux in both past and future under changed conditions. The most efficient way to develop the information will be through the application of the general models developed for the Kuparuk River basin. These models will be calibrated through hydrographs already available in Russia and through spot measurements of concentrations of nutrients and organic matter in different types of tundra rivers and streams. These calibration measurements will be best made on samples collected in extensive surveys across the Russian Arctic.

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## QUATERNARY PALEOCEANOGRAPHIC EVOLUTION OF THE WESTERN ARCTIC OCEAN

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The oceanographic history of the Arctic Ocean remains poorly understood due to the complex interaction of atmosphere - ocean, ocean - ocean and land - sea. Pan-Arctic oceanographic reconstruction's are also complicated by the segregation of the Arctic Ocean into the Canada and Eurasian basins by the Lomonosov Ridge (~1400m). The Arctic shelves are a critical link in tying together the oceanographic history of the Arctic Ocean because oceanographic interaction between the Arctic shelves and inflowing intermediate Atlantic and Greenland Sea waters is significant to the deep water evolution in the Canada and Eurasian basins. Therefore the correlation of major intermediate and deep water events in the Arctic basins with significant sea ice and ice shelf events on the Arctic shelves will lead to a better understanding of the paleoclimatic history and paleoceanographic evolution of the Arctic Ocean.

During 1988, 1992 and 1993 the U.S. Geological Survey obtained piston cores and box cores from the Northwind Ridge, a prominent feature extending from the Chukchi Sea continental slope into the Canada Basin, and Canada Basin. The results presented here include data from 1992 and 1993 box core-tops and two cores collected during the 1988 cruise, PI88-AR-5 (NWR5) and PI88-AR-3 (NWR3). In addition, data from a composite core (MR-26) from the Mendeleev Ridge collected during the Soviet Ice Drifting Experiment NP-26 is presented.

Quantitative analysis of modern benthic foraminifer data from 22 box core-tops from the Canada Basin, western Arctic Ocean reveals three significant faunal associations; *Textularia-Spiroplectammina* Association, *Cassidulina teretis* Association, and *Oridorsalis tener-Eponides tumidulus* Association. These faunal associations are closely related to the depth distribution of the Arctic Surface Water, Arctic Intermediate Water and Canada Basin Deep Water, respectively, and are similar to other assemblages described from throughout the western Arctic Ocean.

Piston cores collected from the Northwind and Mendeleev Ridges, western Arctic Ocean provide a detailed Quaternary oceanographic record. The paleomagnetic record from Northwind Ridge core 5 is the most complete, representing the Brunhes and upper Matuyama extending back to ~1 my in which stratigraphic units I through M (Clark et al., 1980) are present. The top of core NWR5 is dated at 5,186 and 4.6 to 5.6 cm is dated at 7,800 (<sup>14</sup>C AMS dated, uncorrected age B.P.) indicating that the top of the core represents Holocene conditions. These chronology data indicate accumulation rates averaging >4mm/ka, the highest sedimentation rates for this region of the Arctic basin at depths of >1000 mbsl. The Brunhes record is marked by six prominent zones of foraminiferal productivity, M1-L3, which contain abundant *N. pachyderma*, benthic foraminifers, and correlate to odd numbered  $\delta^{18}O$  stages, with the lowermost peaks representing stages 19 and 21, and the stages 19-20 boundary occurring at the Brunhes-Matuyama boundary (~780 ka). The foraminifer peaks, lithostratigraphic and sedimentary data have been used to correlate NWR core 5 with NWR3 and Mendeleev Ridge core MR-26.

Modern benthic foraminifer associations were used to assess Quaternary assemblages recovered from Canada Basin margin piston cores. Application of Principal Components Analysis (PCA) and Modern Analog Technique (MAT) using the Squared Chord Distance (SCD) dissimilarity



coefficient to the Quaternary benthic assemblages associated them with their closest modern analogs and Arctic water masses. Results show four benthic foraminiferal zonations marked by three significant faunal events associated with the oceanographic evolution of the western Arctic basin. The *Bolivina arctica* Zone occurs in the upper Matuyama and is represented by a low diversity and low abundance foraminiferal fauna and is followed by the *Cassidulina teretis* Zone. The *C. teretis* Zone is dominated by *C. teretis* with an increased diversity in calcareous benthic taxa, and the lower boundary of this zone is coincident with the Brunhes-Matuyama boundary in the western Arctic to water depths not exceeding 2000 m. This zone represents a significant influx of Atlantic Intermediate Water into the western Arctic Ocean. This is followed by the *Bulimina aculeata* Zone marked by the first significant occurrence of *Bulimina aculeata* accompanied by the first major incursion of *Oridorsalis tener* indicating a productivity event at ~300 ka. At the disappearance of *B. aculeata*, *O. tener* becomes the dominant taxa defining the *Oridorsalis tener* Zone. This zone represents an established Canada Basin Deep Water and Arctic Intermediate Water in the western Arctic Ocean and is coincident with oxygen isotopic interglacial stage 7 (Poore et al., 1993).

This work is currently being supplemented by the addition of data generated from a second generation of cores collected from the Northwind Ridge during Arctic Cruise 1992. Paleomagnetic data from the new suite of cores has confirmed the original interpretation of the NWR5 record and further refined the chronology of the 1992 cores. Future work is planned to establish a refined Pleistocene chronostratigraphy for the western Arctic Ocean, and produce high resolution records associated with the interglacials to include faunal and stable isotopic analyses. These records will be used to compare the western Arctic paleoceanographic record with records from the Arctic shelf regions, as well as the paleoceanographic records obtained from ODP Legs 151 and 163 to develop a pan-Arctic paleoclimatic/paleoceanographic history.

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## THE EASTERN RUSSIAN ARCTIC CONTINENTAL MARGIN: SCIENTIFIC ISSUES

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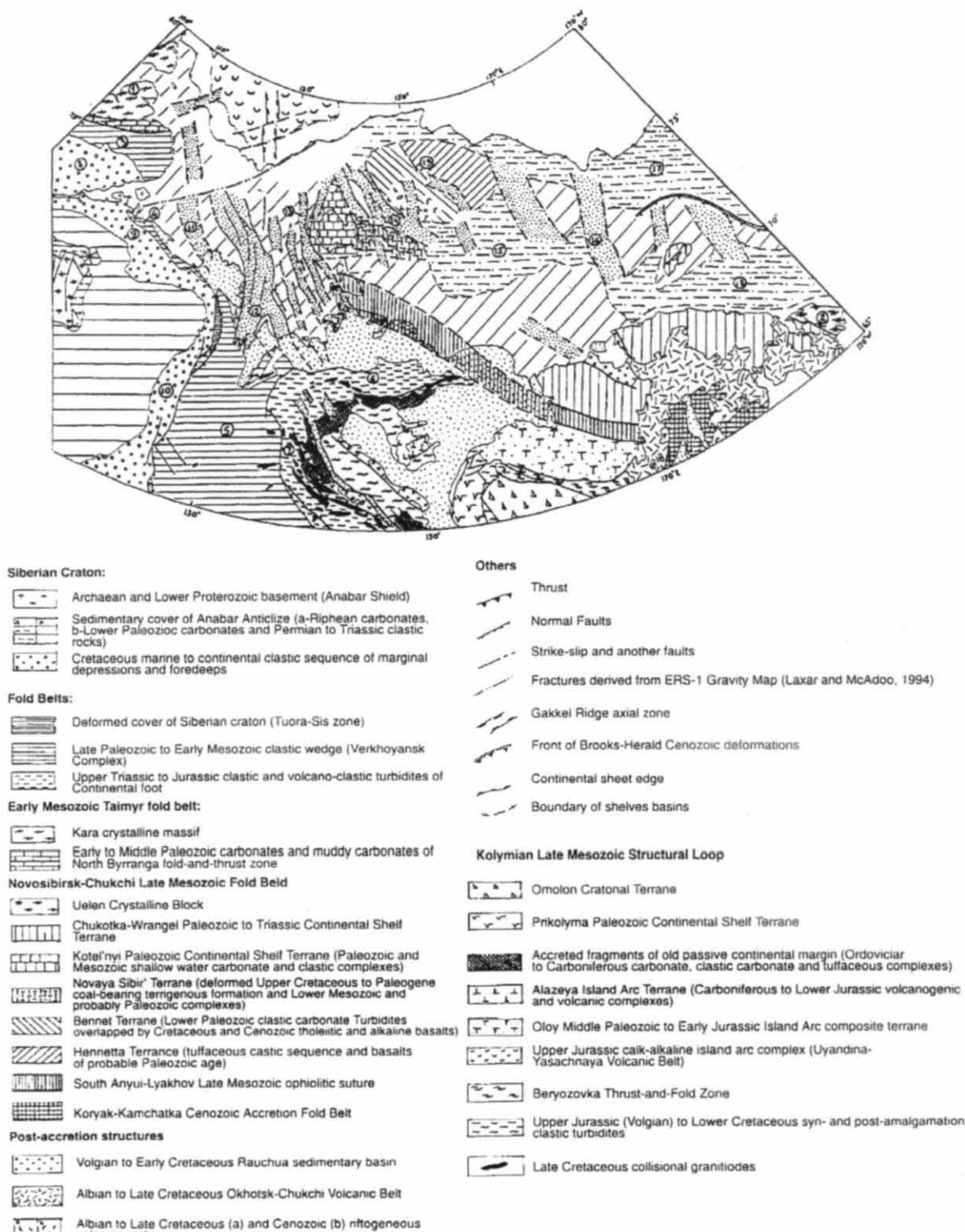
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The East Siberian Sea overlies the continental margin of Northeastern Russia which is up to 800km wide and 1,500,000 km<sup>2</sup> in extent. The geology and history of the shelf are very poorly known and are primarily a postulated extension of the terrestrial geology of the islands and mainland. The Laptev Sea is better known due to the Russian seismic reflection studies which have defined the riftogenic basins (Drachev and Savostin, 1993) (Fig.1). The Laptev Sea is one of two places in the world where an active mid-ocean ridge system enters a continent. This Arctic termination of the North Atlantic Ridge system is near the North American/Eurasian lithospheric plate pole of rotation and thus, the spreading rate is very low at less than 0.35 cm/yr. Laptev Sea seismic data suggest a westward offset of the extension of the Nansen-Gakkel Ridge on the continental shelf and to the east two major rift systems of questionable Late Mesozoic to Cenozoic age (Figure 1) (Drachev and Savostin, 1993). The kinematics of this plate interaction are still unknown.

Fujita et al., 1990 Burke, 1984, and Savostin et al., 1984 suggest that the New Siberian Islands represent an independent plate which rifted from the Canadian Islands in the Late Jurassic and collided with Eurasia along the South Anyui suture zone between Early and Late Cretaceous. The islands themselves are complex and have been divided into five or six separate terranes. These are the Lyakhov Terrane which is a suture zone comprised of a thrust sequence of metamorphic, clastic, ophiolites and calc-alkaline volcanic complexes of different ages intruded by Middle Cretaceous granitoids; Kotel'nyi Terrane is a deformed fragment of old passive continental margin with extensive Paleozoic to Mesozoic carbonate and terrigenous sections; Novaya Sibir' Terrane consists of deformed Upper Cretaceous to Paleogene coal bearing terrigenous formations which is overlain by undeformed Neogene formations and underlain by poorly studied Lower Mesozoic and probably Paleozoic complexes; Bennet Terrane consists of weakly deformed Lower Paleozoic clastic carbonate turbidites overlapped by Cretaceous and Cenozoic tholeiitic and calc-alkaline basalts; Henrietta Terrane is characterized by a deformed tuffaceous clastic sequence overlain by basalts of probable Paleozoic age; The oldest unit on Wrangel Island is the Upper Proterozoic Wrangel Complex of volcanic and clastic rocks with minor mafic and granitic intrusions, the next younger Upper Silurian-Lower Devonian clastic and carbonate formation overlain in places by Carboniferous clastic and carbonate formation with conglomerates, bioherms, gypsum and slate; some upper Permian is present as well as Upper Triassic shales, limestones and an overlying immature graywacke (Kos'ko et al., 1993). All Proterozoic to Triassic complexes of Wrangel Island were penetratively deformed into northward thrust and fold structures during a Late Mesozoic orogenic event. The stratigraphy of Wrangel has been compared to that of northwestern Alaska (Fujita et al., 1990) and is assumed to be part of Chukotka block.

The Amerasia Basin probably formed sometime in the Mesozoic has an enigmatic origin, possibly related to sea-floor spreading with continental remnants (Johnson et al., 1994). There is some

**Figure 1.** Major structural elements of the Laptev and East Siberian Seas based on Fujita et al, 1990, Grantz et al.,1990; Okulitch et al.,1989; and Drachev and Savostin, 1993.



evidence of Cenozoic displacement in the Chukchi borderland (Grantz et al., 1992).

### Scientific Problems

1. Extension of the Laptev Sea rift system onto the coastal plain of Eurasia; origin of the West Laptev sedimentary basin; kinematics of the entry of the mid-ocean ridge spreading center as it enters a continental block. The width of the observed basins equals the amount of crustal extension. This is a unexpected result because normally the width is much greater (Roeser, et al., 1994). If volcanic basement rocks can be identified on the continental shelf associated with the Nansen-Gakkel ridge system, a drilling program would be called for to identify the type of igneous rocks emplaced in this slow spreading setting.
2. The origin and history and interrelationship of the various terranes e.g. did the New Siberian Islands originate in northwestern Canada or partly (Kotel'nyi terrane) in Verkhoyansk passive margin of Siberia? Does the Vil'kitskii Trough which appears as a prominent lineament on the gravity field (Laxar and McAdoo, 1994) represent a plate boundary of the Chukchi Block?
3. What is the origin and nature of the major East Siberian and Chukchi Seas basins ; ie are the New Siberian , Blagoveshchensk Basins and Vil'kitskii Basins underlain by oceanic or stretched continental crust? Have they been connected in the Tertiary or Cretaceous arctic extension phases. New Siberian Basin shows clearly on satellite gravity anomalies derived from ERS-1; however Blagoveshchensk and Vil'kitskii Basins if they exist are much smaller than published data indicate (Fig.1 )( Laxar and McAdoo, 1994). Is the period of extension which formed these basins present in the land geology? If the Canada Basin was formed by Late Cretaceous to Cenozoic spreading where is the accompanying convergent zone on the Siberian mainland?
4. If a Tertiary spreading episode is responsible for the apparent breakup of the Chukchi Borderland what is its manifestation on land and where are the required transform faults? What are the causes, scale, and manifestations of the Tertiary compressive events in the East Arctic continental shelves i.e. Brooks/Herald orocline, Novaya Sibir and Eureka folded zones?
5. From gravity data the South Anyui suture zone appears to strike NW toward Blagoveshchensk Basin rather than toward Bol'shoi and Lyakhov Islands. What is the Lyakhov suture : is it a continuation of the South Anui or an independant ophiolitic joint?
6. What is the detailed history of Cenozoic sea level changes and relationship to tectonism?

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## RUSSIAN GERMAN COOPERATION ON THE SIBERIAN SHELF SEAS: THE LAPTEV SEA SYSTEM

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Establishing the properties and variability of our modern global environment as well as their historic changes is one of the great challenges for mankind. Climatic models and prediction provide one necessary base for securing the future of mankind on Earth. Polar regions are responding fast and dramatically to climate change; their climate record and histories are presently studied with great care (1) to decipher the processes controlling climatic changes of past in great detail, and (2) to monitor ongoing climate changes in real time.

The impact of the polar regions on global climate development has been established some time ago. Modern climate models as well as paleoclimatic reconstructions have shown that the waxing and waning of the continental ice caps and changes in sea-ice distribution influence the renewal of deep and intermediate water masses and, therefore, thermohaline ocean circulation as well. However, our knowledge of the climate impact in the Arctic Ocean, e.g., of the influence of climate changes on sea-ice formation, is very limited, thus making it difficult to predict possible future global climate changes. This holds true in particular for the Siberian shelf seas, which, for logistical and political reasons, have long been inaccessible to the international scientific community. Large amounts of Arctic sea ice are formed on these shelves, thus underscoring the central importance of these processes for the climate system. In its role as source area for the Transpolar Drift and of sediment loaded sea ice, the Laptev Sea is of particular interest. In this region it is possible to demonstrate the extent to which global ocean circulation and, as a result, climate development are also influenced by extremely large amounts of freshwater transported into the Arctic Ocean through the Siberian river systems. Current oceanographic models have not yet taken such a direct terrestrial impact on the global climate into consideration.

The Russian scientific community has a long tradition in working on the Siberian shelf seas because of oil, gas and mineral resources found there and the economic advantages of the Northern Sea Route. Much data and numerous papers have been published, but only a small number of Russian scientific reports have been translated into a western language. Apart from data from American research programs in the 1960's and some recent results from the Arctic Ocean which clearly point to the Siberian Shelf seas in their central importance for the Arctic, little is known about the complex geosystem of the Laptev Sea. However, in 1994 a major interdisciplinary research program 'Laptev Sea System' was designed between Russia and Germany to understand the Arctic environment and its significance for the global climate. Ongoing bilaterale research activities are including land and marine expeditions to the Laptev Sea area during different seasons of the year, workshops as well as the exchange of scientists. The GEOMAR Research Center for Marine Geosciences in Kiel, Germany, and the State Research Center for Arctic and Antarctic Research in St. Petersburg, Russia, are jointly responsible for organizing and coordinating the project, which is funded by the Russian and German Ministries of Science and Technology.

The scientific basis for this program was established during the years 1991 to 1993. Three



expeditions, AMEIS to Kotelnyy in 1991, ESARE to Tiksi (Lena Delta) and the New Siberian Islands in 1992, and TRANSDRIFT I to the Laptev Sea in 1993 which were carried out in close cooperation with the Arctic and Antarctic Research Institute in St. Petersburg, constituted an important pilot phase of these studies and allowed to build up excellent scientific contacts with our Russian partners.

Research activities in the scope of the 'Laptev Sea System' are devoted to the following scientific aspects:

1. The Laptev Sea is farthest away from the influence of the Atlantic and Pacific water masses whose properties can be followed both in terms of oceanography and biology from the Barents Sea (Atlantic influence) and the Bering Sea (Pacific). The Laptev Sea is henceforth the most Arctic of the wide Eurasian shelf seas.
2. The Laptev Sea oceanography is characterized by an intensive interaction between the marine water masses of the Arctic Ocean and the river run-off from the Lena River and a number of other large rivers draining the Siberian shield areas and adjacent land regions. Sediments of the Laptev Sea floors should reflect this influence through their variable composition.
3. The Eurasian shelf seas are some of the largest shelf seas of the World Ocean. Because of the peculiar climatic situation of the Arctic Ocean the circum Arctic shelves are believed to be places of the formation of cold, saline and oxygen rich brines which cascade across the continental margins into the adjacent deep-sea basins, henceforth, influencing the oceanography of the northern hemisphere polar deep-sea basins. These brines seem to influence the morphology and physiography of the deeper parts of the continental margins through gully, channel and canyon formation as well as the deposition of large quantities of turbidites in the Arctic deep-sea basins.
4. The ice margins of the Arctic ice pack and of the coastal fast ice are subject to extreme seasonality. This is particularly well developed under the influence of the seasonally highly variable run-off of the Lena River.
5. The nutrients contributed by the rivers to the Arctic shelf seas are resulting in a considerable biological productivity despite the extreme living conditions which have developed in the Arctic Ocean.
6. Recent investigations of the flaw lead separating the coastal fast ice from the drifting Arctic ice pack have shown that the Laptev Sea is one of the most important "ice factories" of the entire Arctic Ocean. Here new ice is continuously formed which is then contributed to the Transpolar Drift and which is transporting large quantities of sediment included into the ice due to the peculiar ice-formation processes (frazil ice) in the Laptev Sea.
7. The monitoring of the extent of the Arctic ice cover since the beginning of this century has shown that the global temperature increase during the past decade have seen a response in a reduction of the ice cover. The Eurasian shelf seas, in particular the Laptev Sea, might therefore be excellent objects to monitor the impact of Global Change.
8. The history of the Laptev Sea during the geological past is particularly interesting because this region was properly located to the east of the large north European ice shield. Its paleoenvironmental variability is influenced by the changes of the river run-off from the large Siberian land masses by eustatic sea-level changes and by the impact of tectonics of the young intersection of the active mid-ocean Gakkel Ridge and the underlying continental basement.

## SIBERIAN RUNOFF AND GLOBAL CLIMATE

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Recently, Shaffer and Bendtsen (1994) suggested that eustatic changes of the sea level during the glacial - interglacial transition could significantly influence the flow of North Pacific water through the Bering Strait to the Arctic Ocean. The increased inflow of relatively fresh North Pacific waters would decrease surface-water salinity in the North Atlantic and suppress formation of North Atlantic Deep Water. During the high sea level stand at the last interglacial period (125 thousand years ago), such increased flow through the Bering Strait could have been favorable to thermohaline "flipovers" events and might explain the large variability in North Atlantic interglacial climate (Dansgaard et al., 1993).

Another factor that could significantly influence the conveyor belt circulation is a change of the runoff from Alaskan, Canadian, and Siberian rivers. Unfortunately, a direct technique does not exist for the reconstruction of paleorunoff by pollen or other proxy markers. However, some evidence for higher river runoff into the Arctic Ocean during the last interglacial (at least for the drainage basin of the Siberian rivers) can be found in palaeoreconstructions of precipitation and temperatures for Northern Europe and Siberia (Velichko, et al., 1993; Frenzel et al., 1992; Borzenkova, et al., 1992). According to these reconstructions (mainly based on paleofloristic data), the mean annual precipitation in the drainage basin of Siberian rivers was 200-100 mm higher (~1.5 times as much as at present) during the last interglacial. Since  $\text{Runoff}(R) = \text{Precipitation}(P) - \text{Evapotranspiration}(E)$ , changes in the runoff also depend on changes in evapotranspiration. The runoff ratio  $G = (P - E)/P$ , gives an estimate of the fraction of the precipitation that is involved in the runoff ( $R = G \cdot P$ ). The runoff ratio is strongly dependent on the type of vegetation. During the last interglacial period and Holocene, the taiga boreal forest did expand at the expense of tundra (Frenzel, et al. 1992; Borzenkova et al. 1992), and the tree line reached the shore of the Arctic Ocean. Therefore we can expect significant changes of the runoff ratio in the drainage basin of the Arctic Ocean during the interglacial periods. To derive preliminary estimates of the dependence of  $G$  on amount of precipitation in the boreal forest area, 16 monthly averaged hydrological records of last 40-50 years from the Ob, Lena and Yenisey rivers were analyzed. The result of this analysis was compared with known data on the hydrological records from the Canadian rivers of taiga zone. It was found, that the correlation between runoff coefficient and amount of mean annual precipitation is relatively high (coefficients of correlation are in the range from 0.6 to 0.8) and quite similar at the both sides of the Arctic Ocean. The increase in precipitation leads to an increase in the runoff ratio. Since the mean annual precipitation in Siberia during interglacials was higher than present and the taiga forest expanded to the Arctic shore, we can use the present values of the runoff ratio ( $G$ ) in the taiga zone to estimate a minimal sensitivity of Siberian runoff to precipitation changes ( $\Delta R = G \cdot \Delta P$ , with  $\Delta R$  and  $\Delta P$  representing deviations of runoff and precipitation from their present values). The present mean values of the runoff ratio for the taiga basins of Siberian rivers is from 0.24 (Ob) to 0.46 (Lena). A precipitation increase of 200 mm would lead to an increase of the Siberian runoff from 50 ( $G=0.24$ ) to about 90 ( $G=0.46$ ) mm. At present, the evaporation - precipitation difference in the Siberian region is about 100 mm per year, which produces a discharge of 0.12 Sv (1 Sv = 1 million cubic meters/s), ~ 60% of the total river

flow into the present Arctic Ocean (Korzun, 1978; Baumgartner and Reichel, 1975). Thus, the Siberian runoff during the last interglacial is estimated to have been at least 25 or 50% greater than at present (the absolute increase of the discharge is from 0.03 to 0.06 Sv).

According to Shaffer and Bendtsen, the maximum flow of oceanic waters through the Bering Strait at 125 kyr could have been 0.1 Sv greater than at present, with a freshwater equivalent of only 0.006 Sv (based on the present 2 per mil difference in salinity between the North Atlantic and North Pacific oceans). This freshwater flux is from 5 to 10 times less than the estimated changes of Siberian runoff. There are not yet any spatial reconstructions of the precipitation patterns of the Canadian shore of the Arctic Ocean for the last interglacial. However, the expanded extent of broad-leaved forests in northern Canada during the last interglacial proves that precipitation in this region was, perhaps, as high as in Siberia (Mott, 1990). Thus, the total increase of Siberian and Canadian runoff into the Arctic Ocean could have been at least an order of magnitude greater than the increased freshwater carried through the Bering Strait. Therefore, the cause of the larger climate variability during the last interglacial in the North Atlantic is more likely to have been related to precipitation and river runoff into the Arctic Ocean, rather than to North Pacific water flow through the Bering Strait.

Finally, even more significant changes in the Siberian runoff could occur in the near future if anthropogenic warming will lead to an increase in precipitation of drainage region of the Arctic Ocean.

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## RUSSIAN ARCTIC RESEARCH STATEMENT QUATERNARY GEOLOGY - CRYOSPHERE INTERACTIONS

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The Arctic is sensitive to climate change, in part because of feedbacks tied to changeable boundary conditions (e.g. albedo, sea ice, snow cover, forest/tundra boundary) and heat and water exchange between the cryosphere, atmosphere, and ocean. Large variations in these spheres have occurred during the Quaternary in the western Russian Arctic; large marine-based ice sheets grew and decayed (e.g. Grosswald, 1980; Elverhøi and Solheim, 1987), sea-ice cover waxed and waned, and oceanic and atmospheric heat transports from the Atlantic region varied dramatically (e.g. Lehman et al., 1991, Veum et al., 1992). However, the timing and extent of these variations, and their interactions are poorly known; so poorly known that time-slice paleoenvironmental reconstructions from the western Russian Arctic cannot be reliably used as input to numerical climate models.

### **Past Research on Svalbard**

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During the 1980's, INSTAAR researchers assembled a glacier and climate history for western Svalbard during the Quaternary (e.g., Miller et al., 1987; Miller et al., 1989; Forman, 1990, Lehman and Forman, 1992). The paleoclimate history of Svalbard has important implications for the paleoclimate of the western Russian Arctic, especially with respect to the Barents Sea Ice Sheet (BSIS), which may have covered Svalbard at times. Glacier fluctuations on Svalbard were studied using geomorphic and litho- and bio-stratigraphic records, relative sea-level changes, radiocarbon dating, and amino acid geochronology. Seven discrete glacial events were found, the oldest of which was early Quaternary in age. The last deglaciation occurred in two steps, an initial period of retreat from ca. 13 to 12 ka and a later period from 10 to 9.5 ka. The two-step deglaciation occurred during intervals of accelerated global ice-sheet melting and rapid oceanic and atmospheric warming in more temperate latitudes of the circum-Atlantic region. This coincidence most likely resulted from a contemporaneous increase in the poleward transport of oceanic heat during a time of relatively high summer insolation. Curiously, poleward transport of oceanic heat and moisture may be a necessary condition for the buildup of the BSIS (e.g., Hebbeln et al., 1994), and other polar ice-sheets (e.g., Miller and De Vernal, 1992). However, the growth phase of these ice-sheets appears to occur during relatively low summer insolation.

### **Present Research on Franz Josef Land**

*(supported by NSF Grants DPP-9001471, OPP-9223493 and ONR Grant N00014-92-J-1908.)*

Our Russian Arctic research program, started in 1991, is a collaboration between INSTAAR (Gifford Miller, David Lubinski), Byrd Polar Research Center (BPRC; Steven Forman, Leonid Polyak, Francis Herlihy, and Richard Wiehe), and the Murmansk Marine Biological Institute (Gennady Matishov, Sergey Korsun). The main goal is to study the Quaternary glacier and climate history of the Franz Josef Land Archipelago, northern Barents Sea (Fig. 1). The INSTAAR group is collaborating on a study of the relative sea-level and deglacial histories for



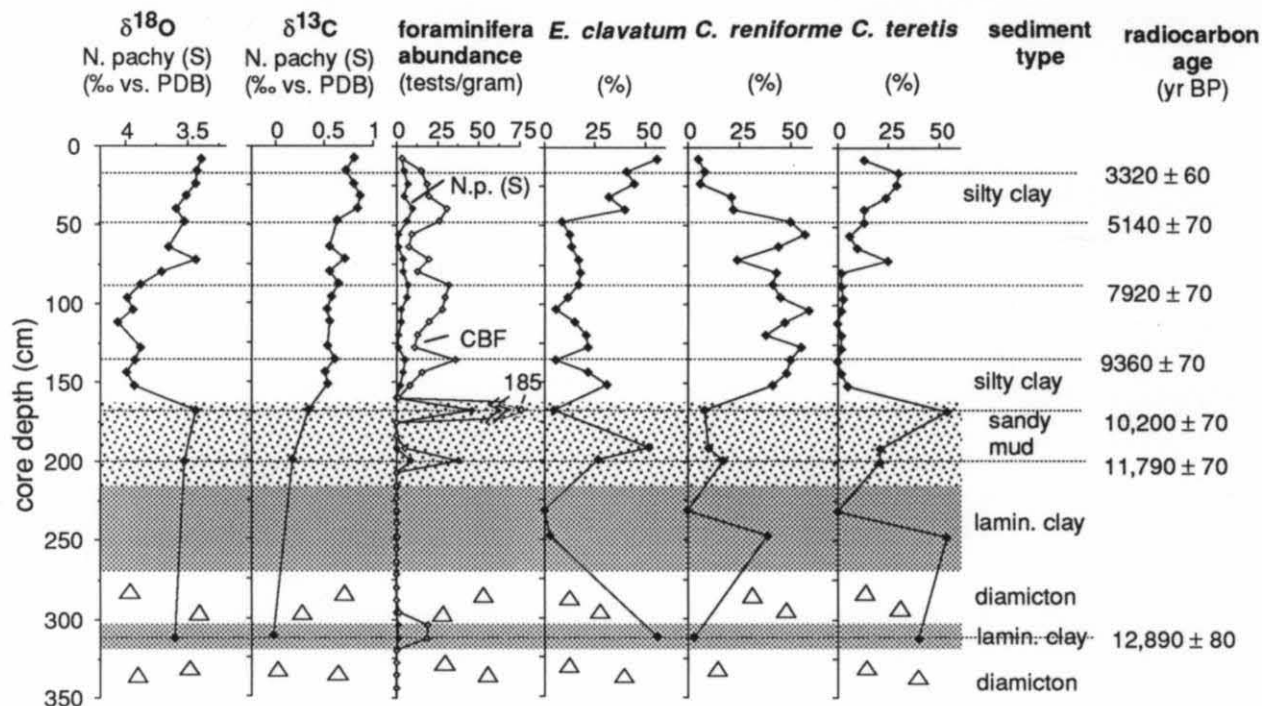
Franz Josef Land (see Forman, this volume) which has already provided new constraints on the magnitude and timing of the Barents Sea and Kara Sea ice-sheets during the Late Weichselian (Forman et al., in press). INSTAAR is also leading several other collaborative studies, including an effort to assemble marine paleo-environmental records of deglacial and post-glacial conditions of Franz Josef Land and the nearby Franz Victoria Trough. We are also evaluating late Holocene glacier fluctuations, and the interactions between changing marine surface water conditions and glacier activity. By reconstructing marine and terrestrial records of environmental change we expect to increase our understanding of the causes for millennial-scale climate change in the western Russian Arctic.

Our study of the BSIS deglaciation has centered on two piston cores (P1-91-AR-JPC5 & JPC6) collected in 1991 from the Franz Victoria Trough (FVT, ~465 m water depth, Fig. 1; Lubinski et al., in prep). Both cores contain silty diamicton at their base, interpreted as ice-proximal glacial marine sediment or till, which suggests that the Barents Ice Sheet was grounded in parts, if not all, of the northern Barents Sea. Eight accelerator mass spectrometer (AMS)  $^{14}\text{C}$  dates on overlying sediment indicate that retreat began in the northern Barents Sea at or before 12.9 ka and that hemipelagic sedimentation began 10.0 ka (Fig. 2). Close-limiting  $^{14}\text{C}$  dates on deglaciation elsewhere in the northern and eastern Barents Sea are ca. 13 ka, suggesting that retreat of the ice-sheet margin began near that time. Any substantial contribution from these areas to the light  $\delta^{18}\text{O}$  meltwater excursion observed in the Nordic Seas, Fram Strait, and the Arctic Ocean (Jones and Keigwin, 1988; Koc and Jansen, 1994; Stein et al., 1994) about 15 ka ago must have been due to drawdown of the ice sheet, rather than marginal recession. Oxygen isotopic ratios in planktonic foraminifera *N. pachyderma* (sinistral) from FVT at 12.9 ka, 11.8 ka, and 10.2 ka were about 0.4‰ lighter than after 10.0 ka, implying local deglacial meltwater production. Foraminiferal assemblages at these times suggest an early occurrence of Atlantic-derived intermediate water.

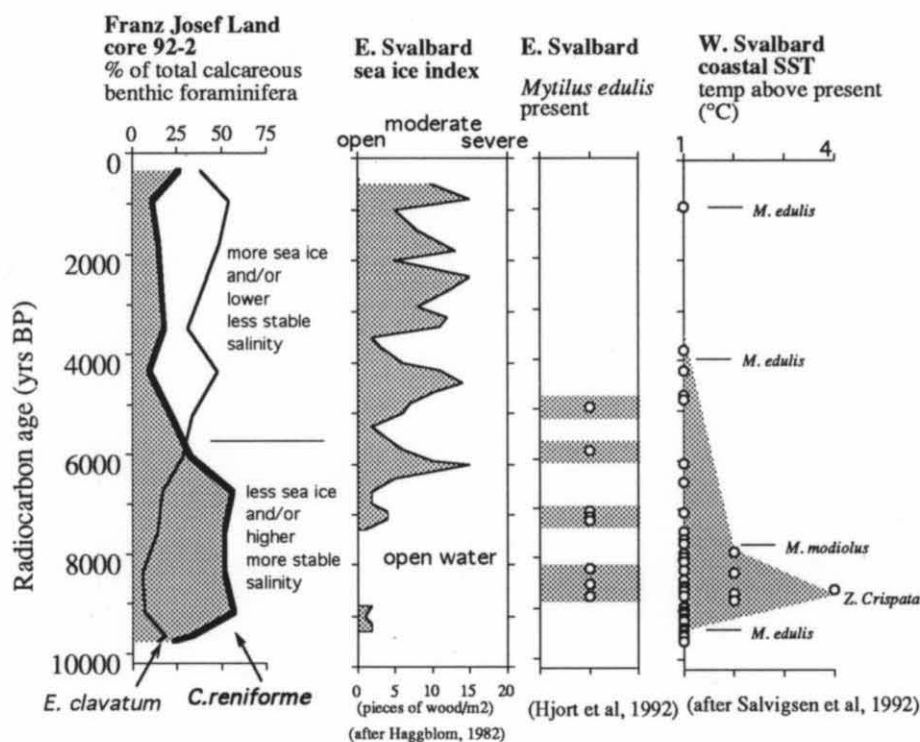
Our study of post-glacial environmental change has centered on the Holocene section of piston core JPC5 and four gravity cores taken from the deep (>300 meters) inter-island channels of Franz Josef Land (Fig. 1; Lubinski et al., in prep). Benthic foraminiferal assemblages in these cores are dominated by *Cassidulina reniforme* from 9.5 to 6 ka and by *Elphidium clavatum* (identical to *excavatum* f. *clavata*) afterward (Fig. 3). These foraminiferal zones suggest that the early Holocene, relative to the late Holocene, was characterized by higher and/or less variable bottom salinity and/or less sea-ice cover. Both of these conditions could occur with increased Atlantic surface or subsurface water influx during the early Holocene. Alternatively, reduced sea-ice cover could be caused by increased insolation alone or combined with a greater Atlantic water influx than at present. Our benthic foraminifera record agrees qualitatively with nearby Svalbard records of sea-ice cover (Häggblom, 1982) and coastal surface temperature (Hjort et al., 1992; Salvigsen et al., 1992; Fig. 3). These nearby records show low sea-ice concentration and the occurrence of thermophilous molluscs in the early Holocene when *C. reniforme* dominates, followed by generally heavier sea-ice concentrations and lack of thermophilous molluscs when *E. clavatum* dominates.







**Figure 2.** Downcore plots of stable isotopic and foraminiferal results for JPC5. Foraminiferal abundances and percentages, including those of *N. pachyderma* (S) (N.p. S) and calcareous benthonic foraminifera (CBF), were calculated from the > 125  $\mu\text{m}$  fraction.  $\delta^{18}\text{O}$  is relatively light (3.5‰) during deglaciation and is followed by a rapid 0.4‰ increase coincident with the glacial marine to marine sediment transition. The latter part of deglaciation (10.2 ka) is marked by an abundance maximum for both benthonic foraminifera and planktonic foraminifera. Data from Lubinski et al. (in prep).



**Figure 3.** Holocene marine environmental data for the Northern Barents Sea and Nordic Seas. Times of relatively less sea-ice cover and/or higher salinity in Franz Josef Land (represented here by core 92-2) are roughly correlative with occurrence of openwater conditions on E. Svalbard (Hopen Island), *Mytilus edulis* on E. Svalbard, and elevated SST's in W. Svalbard (reconstructed from mollusc assemblages).

Most of the archipelago is presently ice-covered (>85% glacierized). Our study of late Holocene glacier fluctuations on Franz Josef Land is based on rare moraines, and vegetation emerging from beneath retreating ice margins (Fig. 1; Miller et al., 1992B; Lubinski et al., unpublished). Our interpretation of the radiocarbon dates and additional historical data show that ice margins do not always advance or retreat in phase. However, there are common trends in ice extent. For example, there is evidence on two islands for one or more "Little Ice Age" advances between ca. 600 yr BP and ca. 300 yr BP. There is stratigraphically-constrained evidence from three islands for a Neoglacial advance between 1200 yr BP and 750 yr BP. Fragmentary evidence exists for advances ca. 2100 yr BP and  $\geq$  3200 yr BP. Ice margins in the middle and early Holocene are less-well known. In many areas ice was generally behind present limits from ca. 9000 to 5000 yr BP. However, marine limits on several island are ca 5500 - 6000 yr BP, which could indicate residual ice during the early Holocene, or, alternatively, the young marine limits could be caused by delayed emergence due to a thin ice load and a rapid reduction in global sea-level rise near 6000 yr BP. In general, the record of ice margins on Franz Josef Land resembles that of Svalbard, with reduced ice in the early Holocene and increased ice extent in the Late Holocene. This history may suggest that relatively high insolation in the early Holocene, combined with increased poleward transport of oceanic heat and moisture (e.g. Koc et al., 1993), led to net mass loss for the glaciers.

### **Compelling Quaternary Research**

Successful research by the international community in the Russian Arctic will require a strong collaborative component from colleagues in the Russian scientific community. It will be important to not only identify important scientific questions that can be best addressed by directed research in this region, but to also identify Russian colleagues who can contribute to the inquiry, and to involve them in the earliest planning phases of the research. Sustained research activity in Russia almost certainly hinges on successfully engaging Russian colleagues in all phases of the research program.

How can Quaternary research in Russia be better incorporated into existing Arctic Science programs like ARCSS ? Which objectives outlined by these programs are the most important and can be studied in the Russian Arctic? As geologists, our primary expertise relevant to the ARCSS science plan is to capitalize on the natural experiments of the last 30 ka to gain a better understanding of the linkages between various components of the Earth system, and to define boundary conditions at various times in the recent past.

Sea ice is both sensitive to, and a cause of, climate change because of albedo feedbacks and hydrological interactions (i.e., freshwater effects on the formation of deep-water). The sensitivity of sea-ice cover to climate forcing is poorly known, as is the variability of sea ice at different temporal and spatial scales. The paleoclimate community can help fill these knowledge gaps by assembling a set of proxy records of sea ice for time intervals with significant changes in sea-ice cover and comparing them to time-series of climate forcing. The Holocene is one such interval for which reconstructions on a century time-scale are possible. AO-GCM runs (e.g., Kutzbach and Gallimore, 1988), a field-based study by Haggblöm (1982) on Svalbard, and our benthic foraminifera records on Franz Josef Land imply dramatically reduced sea-ice cover in the early Holocene relative to the late Holocene (and relative to present). The INSTAAR group will be returning to Franz Josef Land in August of 1995 for a pilot study of Holocene variations in sea-ice cover. We will assemble time-series of driftwood density on the emerged beaches of

Franz Josef Land. Driftwood density in this region is thought to be proportional to sea-ice cover because sea-ice is necessary for transport of the wood from Siberia, otherwise the wood will sink in open water before reaching Franz Josef Land. Driftwood density is just one method that can be incorporated to assess sea-ice cover, other proxies could include planktonic foraminifera, diatoms, coccoliths, and, clay mineralogy. Records from Russia could be combined with existing records from Arctic Canada to improve our understanding of the sensitivity of sea-ice cover to climate change.

The volume of water stored in the Late Quaternary ice sheets of the northern hemisphere remains most controversial for the shallow marginal seas of the Russian Arctic, including the timing, extent, and magnitude of ice sheets on the Russian shelves. Knowledge of these ice sheets is necessary for understanding climate processes and sensitivities. The highest priority should go to a first-order reconstruction that could be used by climate and sea-level modelers. The quickest way to get to a first order reconstruction will probably include studies of relative-sea level on the islands and mainland, geochronology of moraine records near the coast, geochronology of ice-dammed rivers on the southern margins of the ice-sheets, and marine sediment core records on the outer shelf and inner slope. It is important that the working group identify key terrestrial and marine sites (Novaya Zemlya, Severnaya Zemlya, Saint Anna Trough, etc.)

Associated with these ice sheets are the timing and mechanism of their disintegration, particular during the volatile period from 15 to 8 ka BP during which abrupt climate change occurred, and the rapid transfer of water and ice from the Arctic back to the world's oceans. A better record of the timing, rates and magnitudes of these changes will allow a clearer understanding of various feedback mechanisms in the climate system, how the system changes state, and the relative importance of various processes on altering the climate. Providing a continuous time series through this key time series will require sediment cores from lakes and shallow marine settings with sedimentation rates at least 10 to 20 cm ka<sup>-1</sup>. Quantitative paleoclimate reconstructions will require modern calibration studies that relate modern climatologies to modern proxy climate variables (pollen, diatoms, foraminifera, isotopes, etc).

Finally, very high resolution records (annual to decadal resolution) documenting environmental change over the last one thousand or so years will provide essential information on the natural variability of the climate system, especially changes in glacier margins and sea ice duration and extent through the "Little Ice Age". A key underlying goal is a better understanding of the actual climatic controls on glacier mass balance and sea ice extent.

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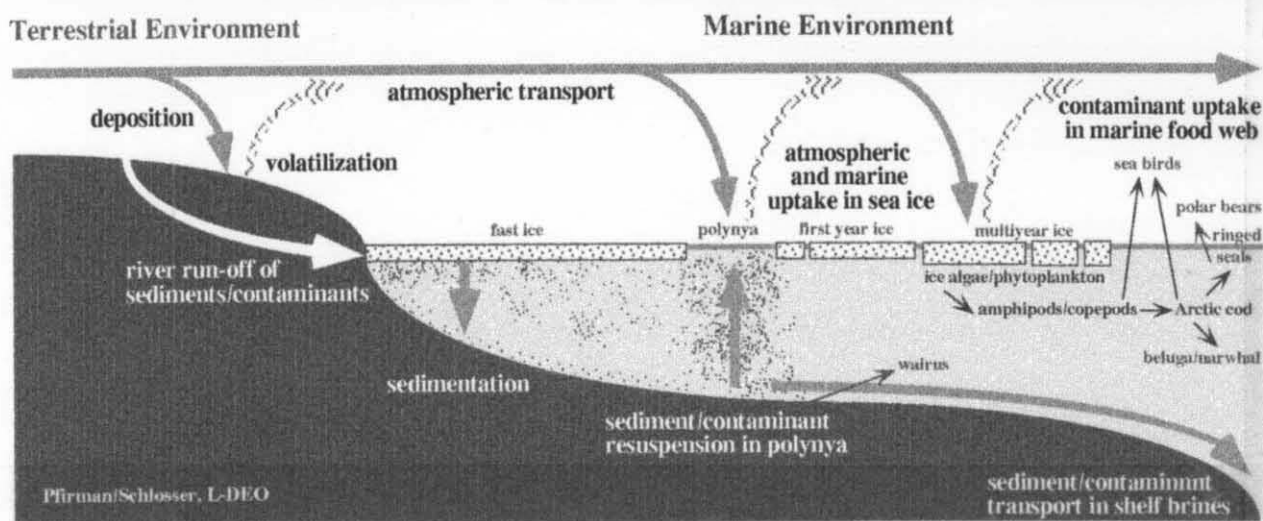
## FLUX OF SEDIMENT, WATER AND CONTAMINANTS IN THE RUSSIAN ARCTIC

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Most of my research to date has focused on understanding sediment transport under modern Arctic environmental conditions. Progressing north with an expedition into the eastern Arctic in 1987, observation of substantial quantities of sediment on the pack ice resulted in investigations to assess its distribution, origin and importance. Research, from this and subsequent expeditions in 1988, 1989, and 1991, showed that sea ice transport is an important aspect of the Arctic sedimentary environment. Most of the sediment is incorporated when the ice first forms at along the fast ice edge of the Siberian continental shelf. Most entrained material represents resuspended sea floor sediments, atmospheric deposition contributes only a minor amount of lithogenic sediment to the pack ice today. Sediment-laden ice that escapes the shelf drifts with the pack across the Arctic Basin and melts primarily in the Greenland or Barents Sea, depositing its sediment load.

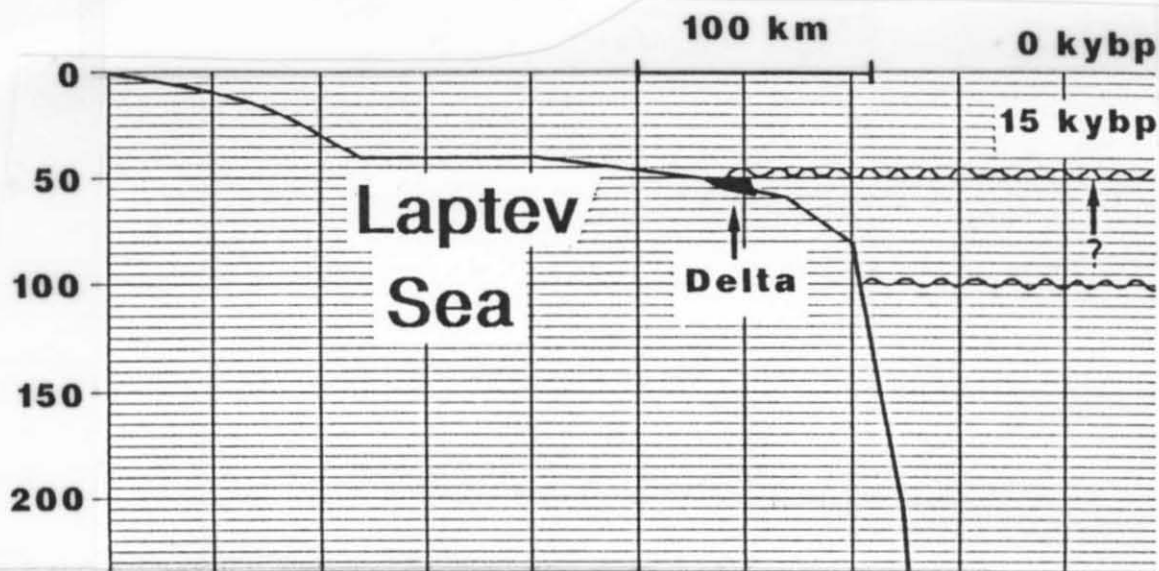
Although the general features of this ice conveyor, which transports sediments from the shallow shelves into the deep basins of the Arctic, are now becoming clear, little is known about sediment fluxes. How much sediment leaves the shelf in sea ice vs. in suspended in oceanic currents? In some regions, e.g. north of the New Siberian Islands and the Central Kara Plateau, sediment entrainment into ice appears to be more active than in other regions. What is special about these areas? Do shelf brines developed by sea ice formation transport significant amounts of sediment off the shelves in benthic nepheloid layers? Surface waters in the Transpolar Drift Stream of the central Arctic are comprised of about 10% river water. Where does this river water exit the shelf and how much sediment is carried with it?

### SEDIMENT/CONTAMINANT CYCLING



Little is also known about changes in sediment transport by sea ice through time. During glacial periods when sea level may have occurred at the shelf break, most of the broad, shallow Siberian shelves would have been exposed. As a result, sea ice would form over deep waters of the Arctic Basin, and would only be able to incorporate sediments from atmospheric deposition and along the narrow coastal zone of the steep upper continental slope. As sea level rose, the shelves would gradually flood, permitting massive sediment entrainment as the shoreline migrated back across the shallow shelves. Little is known about river input during this time: some Siberian rivers were diverted to the south during the glacial maximum, while others may have experienced reduced runoff under cold glacial conditions but increased runoff when the glaciers retreated.

Variability during the Holocene on the shelves could have had significant impact on the oceanic environment of the rest of the Arctic Ocean. Climate changes, changes in shelf bathymetry due to differential glacial rebound, as well as changes in the ease of passage through key straits, could alter the flow of important oceanic currents. For example, recent research indicates that the flow of Atlantic water into the Arctic Basin through the Barents/Kara seas may equal the inflow of Atlantic water through Fram Strait. Because the Atlantic water on the shelf is modified by air/sea exchange and sea ice formation, its characteristics differ from those of Atlantic water which has passed north of Svalbard. If the Barents/Kara route were restricted due to bathymetric or atmospheric changes, the circulation pattern would be altered, with less input of warmth into the eastern Barents Sea. As a result, sea ice might have been more extensive, and oceanic species would alter. This could have occurred during the Little Ice Age, while earlier in the Holocene there is some evidence that the Atlantic water inflow was greater.



Holmes and Creager, 1974  
Biryukov et al., 1988

In the future, warming due to the enhanced greenhouse effect is expected to be greatest in the Arctic. At the same time, precipitation is predicted to increase, by perhaps 15%. Such changes could alter where and when sea ice forms, changing patterns of brine formation and water mass modification as well as ecological distributions. In addition, ozone depletion in the Arctic is second only to the Antarctic, organochlorines and heavy metals are building up to harmful levels in some parts of the Arctic ecosystem, and high level radioactive waste dumped by the former USSR in shallow Siberian waters is causing circumpolar concern.

With growing concern about pollution in the Arctic, it is important to determine where the pollutants come from, and how they move through the ecosystem. At present, our knowledge of pollutant cycling is limited, impairing our ability to predict environmental responses. However, there are some indications that sea ice may also be important in understanding the distribution of pollutants in the Arctic. Observations of high levels of pollutants in some polar bears, seals, walruses and whales indicate uptake of contaminants through the marine food chain. Sea ice could contribute to this contamination by acting as a lid on the ocean, trapping and transporting atmospheric contaminants, potentially bound to particles on the ice. Because much of the Arctic sea ice forms along the Siberian fast ice border, contaminated river discharge as well as sediment may be entrained during formation. These pollutants would then be released during drift and melting, potentially contaminating the ice fauna, and thus the rest of the marine food chain.

## HOLOCENE PALEOCEANOGRAPHY OF THE BARENTS AND KARA SEAS

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Distribution of sea-ice and water masses in the Arctic strongly affect the energy balance in the Northern Hemisphere and global thermohaline ocean circulation. Major factors controlling the formation of sea-ice and water masses in the Arctic Ocean are continental run-off and advection of Atlantic water. Eurasian epicontinental seas receive the largest part of Arctic run-off and Atlantic-derived water, and are major sites for the formation of sea-ice, as well as surface and bottom Arctic waters. In particular, Kara and Laptev Seas receive half of the total Arctic river discharge and consequently produce the largest amount of ice. At the same time, Barents and northern Kara and Laptev Seas are strongly affected by Atlantic-derived water which advects a significant amount of salts and thermal energy. The heat loss of Atlantic water in the northern Kara and Laptev Seas delivers about 11 kcal/cm<sup>2</sup> to the surface water and atmosphere, and decreases the annual formation of ice by 0.5- 1 m (Timofeev, 1963).

The river run-off and the inflow of Atlantic water to the Arctic Ocean fluctuate seasonally and interannually. Observations reveal that the value of Atlantic water inflow is inversely related to the sea-ice cover in the Arctic, and the extent of sea-ice largely covaries with the volume of continental run-off (Nikiforov and Shpaikher, 1980; Zakharov, 1987). At the same time, there is an apparent correspondence between the discharge of Western Siberian rivers and Atlantic water advection, which may be related to coupling between North Atlantic oceanic circulation and atmospheric vapor transfer.

The paleo-record indicates pronounced oceanographic and climatic changes in the Arctic during the Holocene. Particularly strong changes are associated with the North Atlantic climatic optimum; its effect on the Arctic seas is estimated to occur between 9 and 5 kyr BP (e.g. Salvigsen et al., 1992; Lubinski et al., 1994; Polyak and Solheim, 1994). Subsequent cooling is also well recognized, and can be associated with the Neoglaciation in the Arctic.

Our data indicate distinct changes in faunal assemblages and the sedimentation regime in the Barents and Kara Seas associated with the North Atlantic optimum. Foraminiferal assemblages from the interval of 9 to 5 kyr BP have elevated contents of *Melonis barleeanum* or *Cassidulina teretis* and planktonic forms, which suggests increased nutrient flux and Atlantic water advection. Various records of this period from the Barents Sea are also characterized by low sedimentation rates, signs of erosion at the shallows, and increased contents of the foraminifer *Cibicides lobatulus*. These features indicate an increase in hydrodynamic activity, which is apparently associated with intensification of the North Atlantic current.

The presumed maximum of the Atlantic water influence at 7-6 kyr BP corresponds to the light oxygen isotope spike in planktonic foraminifers in our record from Franz Victoria Trough and the Eurasian Basin records (Stein et al., 1994). Oxygen isotope composition in modern Arctic planktonic foraminifers is controlled mainly by salinity gradients (Spielhagen and Erlenkeuser, 1994), which suggests that 18O minimum was possibly connected with an increase in the Siberian river discharge. The coincidence of Atlantic and riverine pulses in the Arctic Ocean during the Holocene would simply the causal relationship between these processes.

Distinct change in foraminiferal assemblages occurred at approximately 5 kyr BP. The increase in the abundance of *Elphidium excavatum clavatum* and other taxa typical for high-Arctic environments suggest the expansion of surface Arctic waters and sea-ice cover. This change was accompanied by an increase in sedimentation rates near Svalbard and Novaya Zemlya, which may be connected with Neoglaciation. This event coincides with the halt in the glacio-isostatic rebound documented for some sites in northern Novaya Zemlya (Forman et al., in press), which also presumes glacial readvance.

Detailed investigations of sedimentary records from the Barents and Kara Seas with rigorous time control are required for deciphering the Holocene history of the Eurasian Arctic. These studies should be aimed at assessing the influence of river run-off, Atlantic water inflow, and glacier readvances on oceanographic and sedimentary environments. Results will provide new understanding of the history and mechanism of environmental change in the Arctic.

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## A NATURAL COMPLEX OF THE SEAS OF THE SIBERIAN SHELF

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The Arctic seas along with deltas and estuaries of the Siberian rivers, being a transient dynamic zone between the water catchment basins and coast on one hand and a deep Arctic basin on the other hand, are considered to be an important link of the natural complex of the Arctic and a specific compartment of the ecological system of the Arctic Ocean.

To rank the problems and find out the priority in the directions of the studies is governed not only by the logics of the development of scientific knowledge but also by the social significance of different aspects of the compartment under study and the dependence of human activities on different natural phenomena. Let us enumerate the main social and geopolitical aspects of the study and exploration of the seas of the Siberian shelf:

1. The islands and the shelf of the Arctic seas have potentially large deposits of minerals and energy resources, and the oil and gas production in the Barents and Kara Seas has become a reality. The resources of the Arctic shelf govern the strategic advantages of Russia.
2. The Northern Sea Route is an important transport waterway of Russia and there are all preconditions toward making it an international shipping route.
3. The Arctic seas and river estuaries are the regions of fishery and of other sea products, thus being important food sources for indigenous people and the nation on the whole.
4. The rivers of the Arctic transport suspended substances and contaminants to the seas and further to the Arctic Basin, which are deposited and accumulate in the shallow regions of the Arctic Seas and in the abyssal Arctic Ocean.
5. Around the Novaya Zemlya island in the Barents and Kara Seas at different depths there are places of radioactive waste dumpings, the state of which is not under control.
6. The human life and activities in the Arctic strongly depend on weather conditions and natural phenomena, while the Arctic nature is especially vulnerable to a technogenic impact.
7. The Arctic Seas and the coast are an open border of Russia and with the development of air, surface and underwater transportation means they attain a new significance in the defence doctrine of the country.

The factors mentioned above provide sufficient grounds to consider the Arctic Seas to be an important natural compartment for Russia and the world community, stimulating the formation of the plans of basic and applied research studies in the Arctic Seas in new conditions. Due to the diverse interests of the subjects the investigators face a wide range of problems. To obtain optimal results at minimum costs is possible only with a comprehensive approach to the problem.

The seas of the Siberian shelf have the following common features: the presence of a shallow shelf for much of the area of the seas, the ice cover existence and its significant seasonal change, a large input of the river run-off, the interaction of the seas with a deep Arctic Basin.

However, each sea has its own specific combination of the depth, bottom relief and coastline, volume and distribution of the coastal outflow, as well, as the degree of being "open" to the Arctic Basin and the adjacent seas. These factors create different conditions for the processes

and form the features of the hydrological regime, different for each sea.

The region, which includes the Laptev and East-Siberian Seas, the Taimyr-Severozemel'sky area and the New-Siberian islands is considered to be one of the most interesting and unique regions of the Arctic.

The following natural phenomena are especially well-pronounced in this region:

- heavy ice of the Taimyrsky ice massif and thick ice of the Aion ice massif, extend like two gigantic "ice arms" alternately synchronously or asynchronously from the Arctic Basin and either block or free the Northern Sea Route in summer; in winter the largest amount of sea ice is exported from the sea area of the region to the Arctic Basin, and due to this it is called the Arctic ice factory; of all the seas of the Siberian shelf it is to the Laptev Sea that the Atlantic water releases the largest heat amount; surface Arctic water stores the "memory" of the freshwater outflow of the Laptev and East-Siberian Seas for a long time and the anomalies of water characteristics are traced in the Arctic Basin as a wide branch up to the North Pole; the water area of the Laptev Sea is a contact zone of the pressure-thermal conditions of the west and the east, and the synopticians call the Taimyr region the cemetery of cyclones; the East-Siberian Sea is the most shallow sea, the continental shoal off the New-Siberian islands extends 600-700 km northward from the mainland coast, being adjacent to the Lomonosov Ridge and here the fast ice width reaches 400-500 km in winter; in winter extensive water areas form behind fast ice, which are called the Great Siberian Polynya; the Laptev Sea is equidistant and it is influenced by the Pacific and the Atlantic oceans, which is the cause for the coexistence of the biological species of the Pacific and the Atlantic provinces in one basin; in the Laptev Sea there is as N. Zubov called it a "life oasis": the herd of the New-Siberian walrus does not leave the sea; there are surprisingly rapid, long and extensive migrations of polar fox and reindeers over vast fast ice and sometimes drifting ice, over the coast, river estuaries, at the Severnaya Zemlya and New-Siberian islands, covering the Laptev Sea by a very rare "live semi-circle"; the deltas and estuaries of the Lena, Yana, Olenek, Khatanga rivers and the adjacent sea areas still preserve populations of valuable and rare fishes, such as sturgeon and sig in large amount; islands disappear over vast shallow areas of the Laptev Sea: the Semenovskiy island transformed into a bank for 40 years, earlier such islands as Vasilyevskiy, Merkurius, St. Diomid, etc. disappeared; and at the Zhokhov island (New-Siberian islands) the most old mesolithic stand of the ancient man in the Arctic was found.

These facts have laid the foundation for the creation and implementation of a joint Russian-German Program "The Laptev Sea System", which has been so far financed on a bilateral basis, but which is open for joining of financial, research and technical resources of any interested participants. The program is oriented to the study of two basic problems:

- the interaction of natural processes within the river-shelf-ocean system in the area of the largest freshwater outflow and sea ice melt; and the geodynamics of the conjunction of the oceanic rift of the Gakkel ridge with the continental shelf of the Laptev Sea.

Table I presents averaged data on the components of the water medium balance. However, the variability of the exchange characteristics is known to be quite large both within a season and from year-to-year.

The variations in the characteristics of atmospheric circulation, run-off of the Siberian

ivers, ice cover extent of the Siberian shelf seas and other interannual variations of the main external factors have a well-pronounced cyclic character and the amplitudes of fluctuations have large values. In particular, for total ice cover extent of the Siberian shelf seas the interannual variability can reach 50% of the normal value of the ice cover extent. Strong variations of the external factors are received and transformed by the sea, being expressed in the specific forms of the development of hydrological processes and the change of the sea system state.

These circumstances indicate that when the sea is identified as a natural compartment for temporal scales of the climatic period the traditionally delineated marine medium should include the near water (near ice) atmospheric layer, coastal zone of a possible sea advance, surface sediment layer at the bottom, including benthos, etc.

The Program "the Laptev Sea System" is an example of such a system approach to the study of the natural compartment. A specific implementation plan has been structured in such a way as to achieve the following main goals of the project:

- to find out the relationships between the processes, occurring on land (geomorphological processes, river run-off, living nature processes) and in the Laptev Sea (sedimentation features, coastal and hydrophysical processes, ice phenomena, biological processes);
- to find out the relationships between meteorological, ice-hydrological, geomorphological, geophysical, biological and ecological processes in present-day conditions and determine the typical features in the variability of the natural environment of the region;
- to investigate the present state and history of the development of marine and terrestrial ecosystems of the Laptev Sea region, to obtain a background picture of the state of the ecosystems;
- to specify the picture of the geological structure of the region, reconstruct the history of its development, paleoceanography, paleoclimatology, to find out the migration pathways of the ancient man;
- to create the theoretical bases of the forecasting estimates of the environmental variability of the Laptev and East-Siberian Seas, the Taimyr-Severozemel'sky area, the New-Siberian archipelago.

**Table I**  
Characteristics of the seas and volumes of the freshwater inflow

<u>Parameters</u>	<u>SEAS</u>		
	Kara	Laptev	East-Siberian
Sea area, th. sq.km	883	662	913
Water catchment area, th.sq.km	6589	3643	1342
River run-off to the sea, km/cm* a year	1350/153	767/116	213/24
Ice volume by the end of winter, cu.km/cm*	1520/172	1490/225	1260/158
Sea ice export from the sea, km/cm*	240/27	540/82	150/16
Ice melt by the end of summer, cu.km/cm*	930/105	650/98	960/105
Atmospheric precipitation, cm/year	35	25	30

\* The numerator presents the volume in km;

The denominator- the layer thickness for the whole sea area, equivalent to the volume.

## OBSERVATIONS AND SPECULATIONS ABOUT ICE-DOMINATED ARCTIC DELTAS: THE LENA RIVER, SIBERIA

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The Lena River discharge ranks second among the large Siberian Rivers draining into the Arctic Ocean. This discharge has resulted in construction of a very large delta, and is influencing deposition and most other processes over the 500-km-wide Laptev Sea shelf. My presentation will raise fundamental questions about the Lena River- and other ice-dominated Arctic deltas, characterized by a unique 10 to 20-km-wide, <2-m-deep platform, called the 2-m bench.

The subaerial Lena River Delta, because it is aggraded to modern sea level, probably was built during the last 5000 yrs, when post-glacial sea level rise stabilized. Now the delta is eroding. What environmental changes have shifted the balance between sediment input and marine and ice forces during the late Holocene time to account for this large relict delta? Does climate change play a role in this enigma?

As in Arctic streams of North America, the bed of the Lena River is characterized by sand, yet sand supply to the sea apparently is insignificant today. Some observations suggest, the long-held theory that river flooding of fast ice produces sediment-laden ice in the Transpolar Drift can finally be dismissed. A major German/Russian cooperative program will focus on the question of how peak discharge of the Lena River, coinciding in time with maximum extent of sea-ice, influences the latter and its unique cross section.

Whether river flood-waters with sediments are forced upward to spread on top of the 2-m thick fast ice depends on channel geometry in the mouths of main distributaries. North American rivers discharging into the Beaufort Sea are <2 m deep, and therefore over-flow onto fast ice (Fig. 1). We do not know channel geometry of Lena distributaries, but new Russian information indicates that flooding of adjacent fast ice does occur. As on the Colville River Delta of Alaska, the bottom-fast ice covering the broad 2-m bench on the Lena River Delta remains submerged for several weeks. The 10 to 30-m rise in river level during spring flood probably causes a rise of sea level on the shallow shelf. This in turn will eventually lift the bottom-fast ice off the sea bed on the 18-km wide 2-m bench fringing the delta. At this time, seaward-flowing currents between floating ice and the 2-m bench may be extremely strong, as reported for the Mackenzie Delta. The planned Lena River break-up study should establish whether the anomalous profile of Arctic deltas, shown by comparison with open-water deltas around the globe (Fig. 2), is caused by such ice-constricted discharge of river flood-waters. As off North America, the previously flooded ice with any sediment cover apparently melts in place. An understanding of these and other Arctic delta processes discussed here will be important for understanding the puzzling erosional delta, and also for learning how any pollutants introduced from this large Siberian catchment area may be by-passed into the Arctic Ocean.



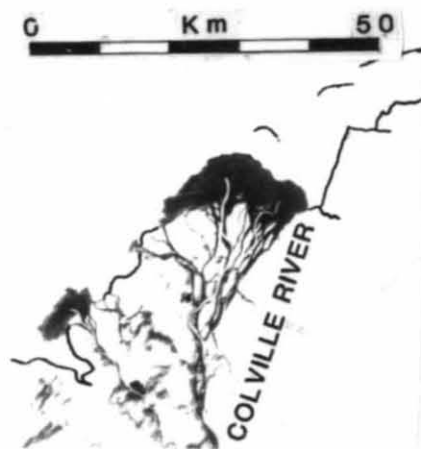


Figure 1.- Landsat image showing the flood waters of the Colville River on the shallow (<2-m) platform (*2-m bench*) typical for ice-dominated Arctic deltas. The sinuous white bands in the flooded region mark channels >2 m deep, where the fast ice has already floated to the surface.

#### DELTA PROFILE

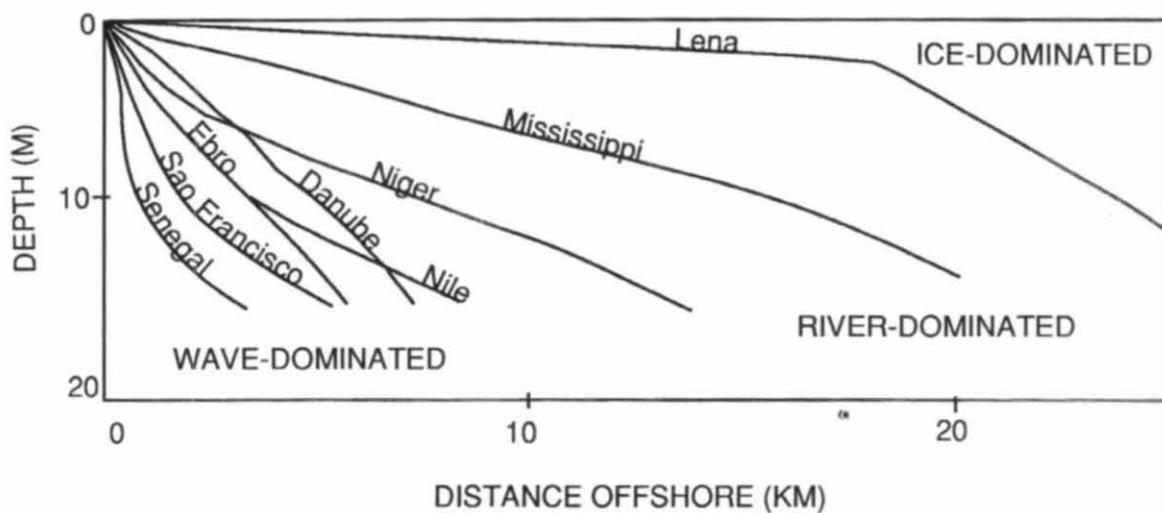


Figure 2.- Seven open-ocean delta profiles after Wright and Coleman (1974) stand in strong contrast to the typical profile of an ice-dominated delta marked by a broad, shallow (<2-m) platform (*2-m bench*) covered by winnowed sand.

## PRODELTAIC DEPOSITS OF MAJOR RUSSIAN RIVER SYSTEMS AS NATURAL ARCHIVES OF INTER-REGIONAL CLIMATE IMPACT COHERENCE

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This proposal aims at investigating the flux of sediment to the prodelta depositional sinks near the mouths of major Russian river systems as a mechanism for evaluating inter-regional impacts of global climate forcing, especially in regard to modulation of hydrological conditions over the past 2000 years (Stream 1 of PAGES). Prodeltaic sedimentary deposits of two river systems that should show distinctive regional "fingerprints" of regional hydrologic characteristics are the Ob and the Yenisey. The Ob drains a large area in western Russia while the Yenisey extends eastward into the central part of the country. Nevertheless, despite their distinctive intra-regional "footprints", the two systems discharge into the Kara Sea in close proximity (Obskaya Guba and Yeniseykiy Zat). The possibility of recovering sediment sections containing a high resolution (year to decade) record of annual river discharge variation in prodelta deposits of these river systems is excellent. Both prodelta facies should be characterized by high net accumulation rates that are often associated with unbioturbated sequences. In temperate regions of Canada, these depositional settings have been shown to contain an interannual proxy record of spring freshet magnitude.

Evaluation of the respective depositional histories of these two river systems addresses the issue of regional uncertainty in regard to the impact of global climate change. Sediment "repositories" with the resolution potential to contribute new understandings to this problem are generally confined to anoxic basins and high net sediment accumulation regimes, which are characterized by reduced bioturbation and maximum (annual to intra-annual) proxy signal resolution. Unlike lake systems that are associated with comparatively small drainage basins, river systems are impacted by global climate changes at intra-regional to regional scales and can therefore provide a realistic record of global climate change impact that is more appropriate for testing the regional uncertainty problem. Extraction of paleohydrologic signals from prodeltaic marine sedimentary records for the past several millennia is dependent on the integrated use of several chronological techniques ranging from varve counts and paleontologic indicators to isotopic methods such as Pb-210 dating calibrated to known historical depositional events (e.g., Smith and Schafer, 1987).

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## THE EARLIEST TRACES FOR HUMAN MIGRATION NORTHWARDS IN EURASIA

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In the beginning of our century Danish geologist Vilhelm Nordmann published his well known book "Menneskets Indvandring til Norden" (Human migration to the North), which was the first attempt to present data upon the migration of Early Man in Northern Europe. Following investigations threw light on these processes in Fennoscandia, and now it is quite evident that the earliest inhabitants of this region moved northwards soon after deglaciation. So even in the beginning of classical Holocene early Mesolithic cultures developed on the northernmost coasts of the Scandinavian and Kola peninsulas. These primitive hunters and fishermen penetrated from the west (Vorren, Martinussen a.o.) as well as from the east (Gurina, Pankrushev a.o.). The earliest peopling of other northern coastlands of Eurasia remained problematic up to very recent time. The present communication gives a short review of new discoveries and their palaeogeographical interpretation.

According to the much promulgated hypothesis of the Panarctic ice sheet (Denton and Hughes, 1981), an enormously huge ice body extended over a considerable part of northern Eurasia during the Upper Pleistocene and even Early Holocene. Nevertheless archaeological investigations in the Pechora Basin and foothills of the Northern Urals showed that these areas had been inhabited by Early Man already during the Late Palaeolithic (Kanivets, Guslitser, a.o.), including the time of the last Pleistocene glaciation. There are similar data from Yakutia (Berelekh site and others).

Thorough archaeological investigations made by L.P.Khlobystin, G.V.Ivanov and their St.Petersburg colleagues demonstrate that Early Man migrated to present coastal lowlands (Bolshezemelskaya tundra) and some large islands (Vaigatch) even during the Mesolithic. The natural conditions of that time were rather favourable for such migrations. Pollen-analytical records from various Arctic areas (Andreev and Tarasov, in press; Malyasova, 1989; Serebryanny and Malyasova, in press.) confirm that at least during the Late Glacial the extent of glaciation was rather close to the present level and during the Early Holocene climate was even warmer than today. The Barents Sea was probably totally ice-free in summer and had rich resources of marine fauna. At the same time coastal lowlands had good conditions for reindeer grazing. Sea level was gradually rising and attained the present position in the beginning of the Holocene climatic optimum, ca.8000 yrs. B.P. In the preceeding time vast shelf areas had a subaerial regime and there were no obstacles for the penetration of Early Man northwards.

Favourable environmental conditions for development of local fishing and hunting cultures existed also in the East-Siberian sector of Russian Arctic. The sensational discoveries of St.Petersburg scientists (Makeev and Pitulko, 1991) in Zhokhov Island, De Long Archipelago, proved the continuous existence of the Great Siberian Polynya (a large area of open water surrounded by sea ice - The American Heritage Dictionary, 1982, p.962) with its rich marine fauna resources during all the late Quaternary. So it is not surprising that primitive hunters and fishermen could move far northwards at least in several regions of the Russian Arctic.

We shall not discuss here the spatial extent of such migrations. Evidently, De Long Archipelago and Novaya Zemlya could be the earliest populated areas in the Russian Arctic in the Early

Holocene. In 1993 G.V.Ivanov published an outstanding paper upon the traces of Early Man at the low terrace of Northbrook Island, Franz Josef Land. From a geographical viewpoint this possibility is not so extraordinary, because differences in natural conditions and food resources were not so great between the southern islands of Franz Josef Land and the western coast of Novaya Zemlya. Final resolution of this question is dependent on future archaeological research.

The early peopling of the northern margin of Eurasia probably was connected with the retreat of large mammals northwards at the Pleistocene/Holocene transition. In Kotelny Island, the largest one in Severnaya Zemlya (North Land), mammoth remains sampled from geological sections were radiocarbon dated at 20,000 to 12,700 yrs B.P. (Korotkevich and Makeev, 1991), but there are much younger dates, 6,000-4,000 yrs B.P., for mammoths from Wrangel Island. As I mentioned in another communication here, terrestrial and marine resources in the southern part of the Arctic Region were quite abundant and available for human exploitation even in the terminal Pleistocene. Finally, I conclude that natural environments stimulated northward migrations of Early Man and in this context the greatest migration of late Palaeolithic people to the American continent may be recognized and explained as quite a normal process. The Panarctic ice sheet hypothesis does not contribute to our understanding of the peopling of the New World at all and seems to be untenable from all viewpoints.

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## QUATERNARY RESEARCH IN THE RUSSIAN ARCTIC: SEDIMENTOLOGICAL AND BIOSTRATIGRAPHICAL VIEWPOINTS

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The changing geopolitical situation in Russia opens new perspectives for extensive Earth science studies in the Russian Arctic helping to incorporate this vast, important region into global and continental international scientific projects. One of the primary tasks embraces climate modelling with special reference to predicting and understanding mechanisms and consequences of the greenhouse effect. To provide realistic information about the events of the past it is necessary to move on an integrated program unifying geophysical, tectonic, sedimentological, biostratigraphical and geomorphological approaches. Such unification will help to overcome still existing obstacles and contradictions and to elucidate the true geological history of the Arctic Region. Because some principal features of its recent tectonic development have already been considered by S.L. Forman and his colleagues (in press), only sedimentological and biostratigraphical aspects will be presented here using some results of recent investigations in the Russian Arctic.

One of the greatest gaps is in the total lack of analytical information upon the genetic types of Quaternary deposits in the Arctic. Due to the efforts of numerous scientists in various countries we can define real characteristics of glacial sediments in temperate regions and even high mountains (e.g. Serebryanny et al., 1989), but we have limited data for such deposits in the Arctic or even for the whole permafrost realm. We do not understand the laws governing the preservation or transformation of glacial tills or other sediment types under the continuous influence of freezing-thawing processes or permafrost.

It is not enough to use only visual criteria for distinguishing the genetic types of Quaternary deposits in the Arctic, primarily because apparent resemblances between some types produce wrong determinations. For example there are some affinities between glacial tills and solifluction covers, and, as the latter are broadly distributed in permafrost regions, occupying sometimes more than 80% of the total area (Naumov, 1993), it is quite possible to exaggerate the true extent of Pleistocene glaciations. Another example is the problem of the extent of continental glaciations in the northern part of Western Siberia and the Pechora Basin. Also our visual geological observations and field measurements made in 1991-92 confirm the marine origin of dominating sediments at least in central axial parts of both regions, only thorough lithological analyses and determination of genetic fields for various sediment groups will give the final solution to this problem.

The possibilities for using biostratigraphical approaches in the Arctic are not so meagre as it was supposed before. The thorough palaeofaunistic research made by V.S. Zarkhidze, O.F. Baranovskaya and others confirmed the broad occurrence of marine transgressions and terraces in polar archipelagoes and continental margins. The palynological research on no less than 230 sections located in the Kanin Peninsula, Pechora Sea islands and Novaya Zemlya I conducted with E.S. Malyasova revealed considerable admixtures of long distance water-transported pollen (e.g. *Picea*) and spores (e.g. *Lycopodium*) in the Quaternary coastal and marine sequences together with redeposited pollen from sedimentary rocks. The regularities of such sedimentation were thoroughly described in a separate monograph (Malyasova, in press).



Nowadays it is possible to trace palaeofloristic records throughout all the Quaternary of the Arctic Region, including several Eopleistocene, Pleistocene and Holocene stages. Clear evidence of continuation between the modern flora and the palaeoflora confirms the lack of large, sharp and continuous interruptions in the development of landscapes and biota in high latitude areas. Present day trends in land/sea extent probably existed throughout the Quaternary. Marine incursions developed close to present coastlands.

During the Eopleistocene there were numerous zonal plant communities in Novaya Zemlya - from meadow coenoses of Boreal type in the Southern Island to Arctic tundras in the Northern Island. The Boreal coenoses revealed in the oldest deposits were rather similar to the Eocene Eoarctic flora described by A.I.Tolmachev (1974). The development of Eoarctic elements accompanied the deforestation of the Arctic Region and transformation of meadow areas into flat tundra plains. A.I.Tolmachev (1974) recognized the Northern Island as a possible dispersal center of Eoarctic flora. Now this prediction is confirmed by pollen analysis.

The Lower Pleistocene palynocomplexes of Novaya Zemlya resemble subfossil spectra of southern tundras of the White Sea Region in their general floristic composition and proportions of particular components. Compared with the Eopleistocene, the climate of Novaya Zemlya had deteriorated considerably, but still remained warmer than today.

Middle Pleistocene deposits are usually depauperate in pollen and spores. Upper Pleistocene deposits, however, contain abundant pollen and spores and two large palynocomplexes can be distinguished: the Kumzha and the Krestyakhino, correlated with well known interglacials and marine transgressions. During the climatic optimum of the Kumzha period southern dwarf shrub tundras existed at the western coastlands of the Southern Island. Later on, they were superseded by herb-moss or dwarf shrub-moss communities of typical tundras. In the Northern Island southern variants of Arctic tundras were typical and glaciation was probably not more extensive than now. The Krestyakhino period was cooler than the Kumzha one and periglacial environments were more distinctly expressed. The climate was slightly warmer than today. During both periods considerable northward migrations of forests occurred in the mainland.

Pollen and radiocarbon data from the western coastlands of Novaya Zemlya do not support the hypothesis of total glaciation of the Arctic Region during the Upper Pleistocene (Denton and Hughes, 1981). Some western coastlands and even inner localities were ice-free during cold intervals. The distribution of refugia in Franz Josef Land and North-Eastern Land, Svalbard, resembled that of today. In addition to periglacial plants (*Ranunculus arcticum*, *Dryas octopetala*, *D.punctata*, *Minuartia arctica*, *Epilobium arcticum* a.o.), some rather thermophilic species like *Rubus chamaemorus*, *Polemonium boreale*, *Valeriana capitata* and *Polygonum viviparum* grew in refugia together with several varieties of *Salix*. Such dwarf willow-herbaceous communities existed close to glaciers. During the coldest stage the Novaya Zemlya ice cover was probably isolated and had no connections with the Ural glaciation, but large outlet glaciers advanced to the present shelf (Pavlidis, 1992).

The study of a series of sites permits reconstruction of specific trends in Holocene vegetational history. In the Younger Dryas and Early Holocene, dwarf shrub communities with high proportions of herbs and Bryales were broadly distributed in the southern part of the

archipelago. Numerous typical periglacial elements still persisted in the flora. Willow and birch prevailed among dwarf shrubs. At the same time Arctic herbaceous-moss tundra was dominant in the northern coastlands.

During the climatic optimum dwarf birch, dwarf willow and Ericales increased in the south of archipelago, and the composition of herbaceous flora was enriched. In the north the proportion of dwarf shrubs was reduced and sedges and grasses grew there together with herbs. As a whole, the role of periglacial floristic elements was less considerable than today.

In the Late Holocene sedge- herbaceous tundra communities occurred on a large scale. The share of shrubs and dwarf shrubs became very small except on south-western coastlands.

During the Quaternary the dynamics of plant communities were mainly influenced by climate changes. The most abundant assemblages of high latitude communities occurred during warm intervals comparable to interglacials. This trend was manifested on an even larger scale during the pre-Pleistocene. However forest vegetation never penetrated to Novaya Zemlya in any of the time-intervals studied, although it undoubtedly could have migrated much further northwards on the mainland than it could today.

Probably none of the Pleistocene glaciations affected all the huge surface of Novaya Zemlya: ice-free areas always existed and functioned as life nuclei even under the most unfavorable ecological conditions. Refugia served as centers of organisms dispersal during deglaciation times. Only by these mechanisms can the development and organization of present day plant communities and landscapes be understood.

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## MAN AND MAMMOTH INTERACTION DURING THE DEMISE OF THE PLEISTOCENE ECOSYSTEM IN THE SIBERIAN ARCTIC

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Drastic environmental changes in the Arctic at the end of the Pleistocene evidently had a crucial influence on early human populations and the peopling of the New World. However, Arctic Siberia could not suggest much of direct evidence relevant to this problem. There was only one late Paleolithic site known in the region, Berelyokh in the lower Indigirka Basin, and it has been studied rather superficially. The Holocene sites, such as Rodinka in the Lower Kolyma Basin, or Chertov Ovrag ('Devil's Gully') on Wrangel Island, seemed too late to be in some way related to the period under discussion. The recent years, however, have been marked by a number of important paleontological and archeological discoveries, suggesting some directions of future research.

The Berelyokh site is dated around 13 ka. It is associated with one of the richest 'mammoth cemeteries', but real relationship between the human lithic culture and enormous bone accumulation is far from being clear. A few radiocarbon dates on mammoth fossils range from 13.7 to 12.0 ka. As far as I know, no direct dates on artefacts are available. Meanwhile, morphological studies of mammoth bones from the cemetery reveal a very wide range of size variation. Most specimens are rather small, and I suggested that during the last 3-4 ka before the extinction some mammoth populations could experience a notable body size reduction. Some specimens from the Berelyokh sample, however, are of the size normal for the late Pleistocene Siberian mammoth. So, the whole sample can be heterogeneous in age. This assumption can be verified by a series of AMS dates on the fossils, which are representative for body size estimation. If confirmed, it will give a chance to trace the trend of body size reduction caused by environmental changes known for that time. Also, the dating program can help to find out true relationships between human and mammoth populations (hunting or fossil bone utilization). There is still a high probability that the Berelyokh people interacted with mammoths in life.

The recent sensational discovery of insular relict population of dwarf mammoth on Wrangel Island has proven that under particular environmental conditions mammoths could survive until as late as 3,700 years B.P. At the same time, the Wrangel case has raised many problems. Mammoths seemed to be quite abundant on the island between 4,000 and 8,000 years B.P. (more than 40 dates), and there are several dates older than 12 ka. No one date is so far known for the period between 12 and 8 ka. According to the evidence from the mainland and other Arctic islands, that was just the time when the most dramatic environmental restructuring in the Arctic took place, viz.:

- a) Radical change in the type of sedimentation on the land (the typical Pleistocene ice-rich silts stopped their accumulation);
- b) Regional outburst of thermokarst processes, and as a consequence, appearance of myriads of lakes on formerly dry surface of the vast plains;
- c) Complete restructuring of vegetation, i.e. demise of the tundra-steppe plant communities;
- d) Disappearance of the characteristic Pleistocene insect communities.

Most of large Pleistocene grazing mammals had got extinct just before or during this period. Mammoth survived in the High Arctic probably longer than the other tundra-steppe mammals,

such as horse, bison, saiga, and woolly rhino, but by 9.5 ka it became extinct everywhere except Wrangel Island. What was really happening at that time on the Island ? It is suggested that the relic mammoth population was supported by relic grassland communities preserved on Wrangel and echoed in modern amazing diversity of herbs and grasses on the Island. However, paleoecological history of the Island is still in the initial stage of research. According to S. Vartanyan (pers. comm, 1993), the available record of the past vegetation is restricted just to the gap in mammoth record, so the reasons for mammoth survival remain hypothetical.

Could any other grazers survive through the early Holocene 'hard times', competing with mammoth for limited resources of the Arctic grassland ? A few available bones from Wrangel are still waiting to be dated.

Could Devil's Gully people, hunters for marine mammals, erect with mammoth ? It cannot be completely excluded (the known time-gap is about 500 years), but seems quite unlikely.

A few years earlier another island in Arctic Siberia, much smaller and remote, has brought a big surprise. An early Holocene hunters' site (9-7.5 ka) has been discovered on Zhokhov Island. Rather unexpectedly, it turned out that the Zhokhov people almost ignored marine mammals, such as seal, or whale, or walrus. They hunted reindeer and polar bear, and their culture display many features of land big game hunters. Also, they made strange tools of mammoth tusks. Before the Wrangel discovery, the very idea that these people could meet a life mammoth seemed impossible, but now this opportunity must be carefully examined by a series of AMS dates on ivory artefacts.

Evidently, the dramatic environmental changes in the Siberian Arctic were to some extent related to the global warming at the end of the Pleistocene. It seems, however, that another, probably even more important factor, must be taken into account, namely, a radical change in the size of the areas occupied by land and sea in course of the sea level rise. Prior to 12 ka, the shore line is supposed to run hundreds miles further north, close to the shelf outer margin. It is quite reasonable to assume that at such a high latitude (75-80° N) the coastal waters were rare (if ever) free from ice in summer. As far as the East Siberian shelf is very shallow and flat, the sea level rise at the end of the Pleistocene resulted in a very rapid southward shift of the coast. Combined with the general warming, this process at some point has led to the appearance of open coastal waters in summers. The presence of huge cold water mass must have become a new and very important regional climatic factor, drastically changing many weather characteristics, such as summer air temperature (-), humidity (+), cloudiness (+), evaporation (-). This climatic change could trigger (if not cause) irreversible destruction of the dry grassland ecosystem on the coastal lowlands of Arctic East Siberia.

If this hypothesis is true, it can prove that the present day lowland tundra - treeless, boggy, mossy, and buggy, and unsuitable for most grazers - is just a coastal, not a 'zonal' phenomenon. In other words, this kind of environment is supported not only by its latitudinal position, but significantly by the influence of the cold water mass of the shelf seas.

To verify this hypothesis, we need to develop a detailed chronology of various events that happened during these critical 5-6 thousand years (13-7 ka). The available record of the vegetation restructuring, extinctions of large mammals (other than mammoth), and human

occupation is still not enough detailed. That is also true for the history of the sea level change in this region, which can be reconstructed from the submerged shore lines, but also from the fossils of marine mammals. A critical issue in the story of human population in Arctic Siberia will be the earliest appearance of hunting cultures based on marine mammals instead of (or side by side with) the earlier dominated land big game hunting cultures.

Evidently, the additional field research programs are necessary at the critical sites, such as Berelyokh, and Zhokhov and Wrangel Islands. However, as an initial step under the limited funding opportunities, a program of AMS dating of the available samples (bone and bone artifacts) will certainly help to solve some of the mentioned problems in the first approximation.

The author apologizes that he could not provide the references to this abstract for technical reasons. The main contributions on the mentioned subjects have been made by the following authors:

General (environmental change in Arctic Siberia, mammoth extinction, human occupation, etc.)	A.Sher, Yu.Mochanov, V.Makeyev & V.Pitul'ko; A.Sher & L.Sulerzhitzky;
Radiocarbon dating:	L.Sulerzhitzky, Kh.Arslanov, A.Lozhkin,
Berelyokh archeology:	Yu.Mochanov;
Berelyokh fauna:	N.Vereshchagin, G.Baryshnikov, I.Zherekhova, A.Sher & V.Garutt;
Wrangel mammoths:	S.Vartanyan, V.Garutt & A.Sher;
Wrangel archeology:	T.Tein, N.Dikov & T.Tein;
Zhokhov archeology:	V.Pitul'ko & V.Makeyev;
Sea level history:	Yu.Degtyarenko et al, V.Ivanov & V.Makeyev; A.Fartyshev.



## IS THERE ANY REAL EVIDENCE FOR A HUGE SHELF ICE SHEET IN EAST SIBERIA ?

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Hypothesis of an 'Antarctic-style' ice sheet in the Arctic (Grosswald, 1984, 1988, and later) implies that during the last glacial maximum extensive marine-based glaciers covered the present shelf of the Laptev, East Siberian and Chukchi Seas, and intruded south onto the coastal lowlands of East Siberia. According to this hypothesis, the islands on the East Siberian shelf were covered by 1 km or more thickness of ice as late as about 15-20 ka or even later. A recent development of this concept (Hughes et al., 1991, Hughes & Hughes, 1994) speculates how this ice overflowing to the Bering Sea could influence the Beringian faunal migrations and peopling of the Americas.

Discussions at the recent Symposium on Problematic Ice Sheets (Stockholm, October 1994) revealed a striking difference in the strength of arguments for the Arctic ice sheets between the West Siberian and East Siberian Arctic. While the scale, timing and detailed pattern of the shelf glaciation were debated for the Barents and Kara Seas, the very fact of the shelf glaciers over the East Siberian Seas was seriously questioned. The present status of discussion on the East Siberian Arctic Shelf Ice Sheet (ESASIS) is briefly summarized below.

Contrary to the Western Arctic with its extensive record of glacial geology, ESASIS hypothesis was never based on real geological evidence except some dubious interpretations of surface topography. It was just theoretically postulated for East Siberia, and its most enthusiastic supporters never conducted field Quaternary studies in the area except brief excursions. The main bulk of previous Quaternary work in arctic East Siberia is considered as inadequate by them as far as it does not confirm the theory. Among the various results of Quaternary research made by numerous workers in East Siberia, which are against the ESASIS hypothesis and are rejected or ignored by its supporters, the following seem the most important:

1. Extremely wide distribution of fine-grained sediments with syngenetic ice wedges ('Yedoma'). They are present all over the coastal lowlands (and even further south) and on the shelf islands, such as Lyakhovskiy, Kotelniy and others. Although the nature of these sediments is debated, and they are most likely of polygenetic origin (fluvial, lacustrine, eolian, slope, etc.), neither glacial, nor marine sedimentation was involved. Accumulation of the Yedoma type sediments is documented both on the lowlands and on the islands since the late Middle Pleistocene times, through the late Pleistocene, until 12-13 ka. They were also being deposited during the Sartanian (Late Wisconsin) times, that certainly could not happen under the 1 km thick ice sheet. Even a wild assumption that all the dates for these sediments are wrong, and they had been deposited before the ESASIS, would not help this hypothesis. The sediments in question have very high content of segregation ice and long vertical ice wedges, and are known to be liable for plastic deformations, but nothing of that kind has ever been reported that could be interpreted as glacial deformations.

2. The youngest (Sartanian) sediments of the Yedoma type build terrace-like surfaces of about 15-20 m above the sea level, including the coastal areas, islands of Severnaya Zemlya, Novosibirsk Islands (Sher and Plakht, 1988; Ovander et al., 1987; Makeev et al., 1979, 1989,

etc). In the lower courses of such rivers as the Kolyma, Indigirka, Yana, fluvial terraces of the Sartanian age are well studied (e.g., Sher et al., 1979). Origination of this topography beneath a thick ice sheet is totally unthinkable.

3. No raised beaches have been reported for the shores of the East Arctic Seas; instead, submerged shorelines are rather widespread (e.g., in the Laptev Sea, cf. Fartyshev, 1993).

4. The strongest evidence against the ESASIS hypothesis is provided by paleoecological studies. Multidisciplinary research suggests the existence of extensive exposed shelf land in East Siberia during the late Wisconsin times. The area including the present coast and shelf islands was occupied by dry grassland communities (tundra-steppe) and diverse fauna of grazing mammals (Sher, 1992). Admitting that 'the only evidence against a marine ice sheet in the East Siberian and Chukchi Seas is a 20 ka date on a single mammoth tooth on Wrangel Island', Hughes & Hughes (1994) miss the fact that this is not the only date of that kind in the East Siberian Arctic. Even if we take only those radiocarbon dates which were obtained directly from woolly mammoth bones, and even if we restrict the sample to the time period between 22 and 14 ka, excluding possible overlapping with the previous warming and the deglaciation, we receive the following (Sher and Sulerzhitzky, MS in preparation): 19.3 ka and 19.7 ka dates on the October Revolution Island, Severnaya Zemlya (Makeev et al., 1979); 15.4 ka, 20.0 ka dates for mammoth on Kotelnii Island, 20.9 ka on Faddeyevskiy Island (Novosibirsk Islands); the mentioned 20 ka date on Wrangel Island; 15.1 ka date from Chukotka (Anadyr Lowland, the Main River); 14.3 ka, 14.8 ka, 17.8 ka, 18.7 ka, 21.3 ka, 22.0 ka, and 21.6 ka mammoth dates from the coastal lowlands between the Taimyr Peninsula and the Lena River. The last date is especially indicative, as it comes from a mammoth bone found in place in a well studied section of the Bykov Peninsula, Tiksi area (Tomirdiario et al., 1984), just a few km north from the only area where the field observations were reported to support the ESASIS idea (Grosswald et al., 1992). 16.3 ka, 20.4 ka, 23.5 ka, and 23.8 ka dates from unglaciated areas of the Taimyr Peninsula. Reliability of radiocarbon dates on bone collagen, especially for the bones collected in the Arctic, has been confirmed by extensive methodological research by Sulerzhitzky (Sher and Sulerzhitzky, MS in preparation).

5. Each time when the broad-scale ESASIS hypothesis is applied to any particular region of the East-Siberian Arctic with the more or less studied Quaternary, it immediately comes to a controversy with the evidence available. That is true for: Severnaya Zemlya, where the area covered by the Sartanian upland glaciers was even less than at present, and the periglacial deposits of the same age are well dated (Makeev et al., 1979); Bykov Peninsula, Tiksi area (see above); Kotelnii Island, with its succession of accumulative terraces (Makeev et al., 1989); lower courses of the Kolyma and Indigirka Rivers with well studied Sartanian terraces (Sher et al., 1979; Sher, 1992); Anadyr lowland with its perfect end moraines confined to the areas of the maximum Pacific moisture input (Sher, 1962; Heiser, 1994); the Bering Sea, where the glacial geology suggests that there is no evidence for glaciers originating on the Arctic Shelf (Heiser et al., 1992; Hopkins et al., 1992).

Summary of all the lines of evidence cited above suggests that the answer to the question addressed in the title can be only negative.

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## PALEOBIOLOGY STUDIES IN BERINGIA

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Beringia in the Holocene has been characterized by rapid climatic and ecological change, drastic restructuring of the environment, and geological modification on a scale surpassed almost nowhere else on earth (Hopkins, 1972, 1973, 1982). The ensuing changes on the surroundings once the icecap began to melt at the end of the last ice age of the Pleistocene transformed the nature of the biological environment with a speed and magnitude unequalled at any time before. Present concerns to understand the biological effects of global change as a result of anthropogenic increases in emission of greenhouse gases and habitat perturbation or destruction compels us to look to the past for evidence of the consequences of large-scale environmental change.

The most promising source of environmental clues is found in the buried residue of the living activities of early Beringian peoples. This material includes food debris, remains of plants and animals used for diverse purposes, collateral adjuncts such as insects, seeds, and pollen that were buried along with the discards, physical and chemical properties of buried soils (eg., isotopes of atmospheric constituents remaining in soil), and carbon sources from peat or charcoal useful for radiocarbon dating. Paleobiological investigations of these kinds of material connected with anthropological study of the human context by which it was buried can give us a richly detailed picture of Holocene changes in Beringia.

In 1990, we formed a multidisciplinary and international team of arctic researchers to initiate an integrated study of paleobiological processes and patterns in Beringia and the Siberian Arctic. members of the team include archaeologists (Debra Corbett, USFWS; Stephen Loring, SI-ASC), zooarchaeologists (Christine Lefevre, Museum National d'Histoire naturelle, Paris), and paleobiologists (Douglas Siegel-Causey, NUSM; Arkady Savinetskii, Russian Academy of Sciences). Since beginning, we have excavated and analyzed material from archeological sites located throughout the Aleutian Islands, Kodiak Island, St. Lawrence Island, and numerous sites along the present-day Bering Straits (Cape Prince of Wales, Point Hope, Anadyr, Sireniki). Our most recent work has been concentrated in the western Aleutian Islands, eg., the Rat Islands and Near Islands groups.

We designed our archeological investigations in the western Aleutians with the goals of understanding the human and biotic paleoenvironment as well as discovering the uniqueness of the early western Aleutian cultures. Accurate reconstruction of early animal and plant communities using materials unearthed from Aleut middens is possible given that there is sufficient knowledge about the ecology of the past occupants (Dinesman, 1986; Savinetsky and Knyazev, 1990). The early inhabitants of the Aleutian Island chain were exclusively maritime hunter-gatherers and coastal breeding seabirds were an important constituent of their diet (Yesner, 1976, 1977). Rigorous comparison of past abundances derived from archeological evidence with present abundances has shown that the early Aleuts hunted seabirds in amounts relative to their biomass (Yesner, 1981), or in other words, they harvested them in the proportions that they occurred in the environment. Thus, it is possible to estimate the past diversity and relative abundance of the marine coastal avifauna of Amchitka Island using



evidence like bird bones found in Aleut middens.

Preliminary results of our paleobiological work in the western Aleutians presage a details biogeographical history of the coastal plants and animals of the Bering Sea. For example, at Amchitka Island, further east of our study areas, we found that the distribution and abundance of breeding seabirds has changed in the last 2,650 ybp (Siegel-Causey et al., 1991). The relative abundances of three cormorant species (Pelagic Shag *Stictocarbo pelagicus*, Red-faced Shag *Stictocarbo uril*, and Double-crested Cormorants *Hypoleucos auritus*) have remained similar throughout the period, and their numbers as found in midden strata have remained relatively constant for the last 1,800 years. By contrast, the numbers of Kenyon's Shag (*Stictocarbo kenyonii*) appear to be increasing, the greatest jump was observed in the last two centuries. One other notable finding was a wing bone of Pallas' Cormorant (*Compsahaleus perspicillatus*), which previously was known only from the Kommandorskii Islands, 800 km to the west. Circumstantial evidence suggests that this species may have bred on Attu Island Nelson, 18??) in historical times, but there is no evidence to support this.

Combined analysis of all bird species recovered from Amchitka middens revealed other patterns. For example, Aleutian Canada Goose (*Branta canadensis minima*) numbers fluctuated widely during the 2,650 years of occupation of site 31. Peak abundances corresponded with climatic maxima during this period; all but one of the population lows corresponded with climatic minima. The single exception to this pattern was for goose bones recovered from the uppermost strata, which was laid down in historical times (Desautels et al. 1971). Although global climate was warming during the period of deposition, goose numbers were extremely low. In fact, out of all breeding species, only Aleutian Canada Geese were significantly lower than expected. By contrast, the numbers of Short-tailed Albatross (*Diomedea albatrus*) did not deviate from the general patterns observed for all birds. In other words, their numbers traced with the overall trends of the entire breeding populations of birds. The exception, however, was again the extremely low numbers of bones recovered from the most recent strata.

For Aleutian Canada Geese, most of their population lows and highs are contrasted precisely by the patterns seen in other species. For example, a population high seen roughly 1,000 years ago is associated with population lows in Slender-billed Shearwaters (*Procellaria tenuirostris*) and auklets (*Aethia* spp.). Similarly, a population low in geese approximately 1,800 ybp was associated with peak abundances for Northern Fulmar (*Fulmarus glacialis*) and auklets. This leads us to suspect that these coordinated changes in relative population abundances is environmental and not caused by human (ie., Aleut) perturbation.

This is not the case with the historical patterns of abundance for geese and albatrosses. The introduction of Arctic Fox by Russian and American trappers in the last 200 years had profound effects on breeding populations and in particular for those birds breeding on flat areas of the island. That is, geese and albatross. This pattern that we observed first on Amchitka Island seems to exist elsewhere in the western Aleutians. We have discovered abundant remains of aleutian Canada Geese and Short-tailed Albatross from midden sites on Little Kiska Island (Rat Islands) and Shemya Island (Semichi Islands) from most strata except those dating from historical times. Interestingly, we found no such drop in abundance at Buldir Island, which never had Arctic Foxes. We can only conclude that population declines in these two species (and others) during historical times is dues entirely to the actions of Europeans.



Our work at present is devoted to getting a clear and much more detailed picture of the relationship of the plant and animal fauna to global climate change, as well as trying to assess the impact human populations may have had on the breeding populations of the western Aleutian Islands. To this end, we are isolating and analyzing traces of DNA left in these bones as a means of determining the population structure of various breeding species during periods of declining or increasing population size. We hope to be able to determine whether overhunting or global change was responsible for the dramatic community change in bird and mammal faunas about 1,200 years ago. During this time, the seabird diversity dropped about 30% and species turnover exceeded 55%, which is indicative of a truly profound reshuffling of the coastal marine bird community.

Other studies in progress include a microquantitative analysis of 20,000 years of continuous peat sequences recovered from Shemya and Attu Islands that focuses on plant and insect biotic changes, isotope analysis of cheated atmospheric gases, soil chemistry, and pyroclastic depositions. In addition, we are reanalyzing biotic material recovered from early archeological investigations in Beringia centered on the Bering Straits and Alaska peninsula. These studies involve reidentification of sample, radiocarbon dating of significant sites and layers, and recovery of proxy material (pollen, seeds, bone fragments, tissue, etc.) from matrix and debitage.

We believe that these types of studies can serve as a window on biotic processes during the late Pleistocene - Holocene in Beringia and Siberian Arctic. Humans are part of the arctic biota, and understanding the paleoecological and anthropological context of the material left behind can help us to understand the consequences of global change in the future.

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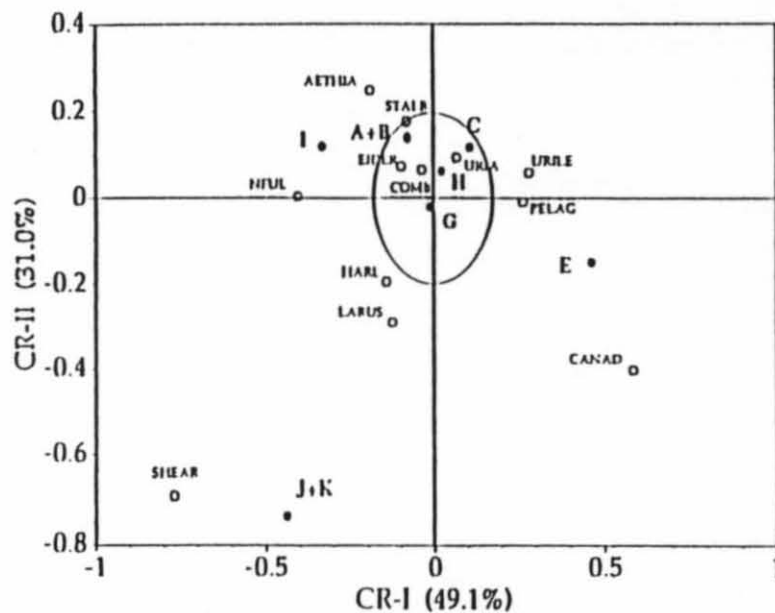


FIGURE 2. Plot of the first two correspondence axes (CR-I, CR-II) describing 80.1% of the total association between midden bones and strata from site 31. The ellipse describes the 95% confidence interval (see text). See Table 2 for explanation of abbreviations.

## SEDIMENT DELIVERY FROM COASTAL SOURCES

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### Introduction

The Arctic setting is sedimentologically distinctive in terms of the importance of ice in mediating terrestrial and coastal sediment properties and controlling the hydrologic and oceanographic conditions which affect sediment transport and deposition. Sediments are supplied to the Arctic Ocean by northward flowing rivers and by erosion of ice-rich unconsolidated deposits along the coast. Sediments are remobilized from temporary storage in prodelta, shoreface, and inner-shelf settings by waves and currents, frazil and anchor ice and grounding sea ice. While this workshop is focussed on the contribution and importance of the Russian arctic land-sea interactions, there is a need to undertake a coordinated study of sediment delivery from coastal sources on a circumpolar basis. This proposal incorporates the need for data compilation on that basis with the requirement to acquire additional new data on the Russian arctic shelves.

At this time, we have a partial understanding of the processes affecting sediment transport and deposition at the coast and across the Beaufort Shelf based on more than 20 years of intermittent of data acquisition. There are likely to be similar datasets in the Russian arctic. The obvious first step is to compile and compare existing data and interpretations so that we can focus future comparative work. There is ample rationale for this type of study through its interaction with IGBP projects like PAGES and LOICZ. It will also provide important information required for long-term conservation and responsible exploitation of these environments.

### Science Plan

#### *1: Coastal mapping*

In order to set the regional studies in a world-wide circumpolar context, we propose to initiate a multilateral effort to map the entire Arctic coast at a scale of 1:2,000,000 (similar in design to the Canada -USSR circumpolar bedrock geology and Quaternary deposits maps). The mapping will focus on geomorphological classification of the coast, geological framework, river inputs, adjacent shelf morphology, climate and ice regimes, among other factors. More detailed mapping will be performed at detailed study sites using existing air photography and satellite imagery. This first phase will provide a better understanding of the problems by allowing assessment of the databases existing throughout the arctic region and based on a comparison of data density, type, and integrity. To some extent this will overlap with work being done by LOICZ and close coordination is important to ensure duplication does not occur.

#### *2: Identification of Russian Arctic locations for detailed study*

In order to quantify sediment contributions from the coast to the shelf and deep ocean, we propose a comprehensive program to acquire information on sediment sources and rates of supply, sediment entrainment and transport mechanisms, dispersal patterns and accumulation rates in sediment sinks along the coast and across the shelf. We propose to implement this program in 1 or 2 key sectors of the Russian Arctic Ocean margin. In each sector, work should extend along the coast and across the shelf, with detailed attention to sites both directly influenced by a river and remote from it. The study will apply and extend methods developed for

use in the Canadian Beaufort Sea to other marginal seas in the Arctic Ocean using the combined scientific knowledge, field experience and logistical resources of those countries on whose territories the work will be carried out, as well as participation from other nations.

One possible site is in the vicinity of the Lena River Delta. The Lena River discharges about  $5.35 \times 10^{11}$  m<sup>3</sup>/a of water and  $1.6 \times 10^{10}$  kg/a of sediment (Gordeev and Sidorov, 1993). According to tide gauge data, it is undergoing isostatic uplift at the rate of about 0.5 to 0.6 mm/a (Borisov, 1973), although, that interpretation appears open to question (Badyukov and Kaplin, 1979). Its general morphology is one of progradation. In contrast, the Mackenzie River discharges about  $3.6 \times 10^{11}$  m<sup>3</sup>/a of water and about  $1.45 \times 10^{11}$  kg/a of sediment (Harper and Penland, 1987), sea level is rising at about 2.5 mm/a (Hill et al. 1993) and the coastline is dominated by erosion of permafrost affected, often ice-rich, unconsolidated material. Thus the Lena River provides about twice as much annual discharge of water and an order of magnitude less sediment relative to the Mackenzie River. The contrast between these two sites will provide fertile ground for a comparative study of the processes controlling sediment storage and transport.

### *3: Data Requirements a Detailed Study Sites*

In order to quantify amounts of sediment delivered to the shelf from the coast, we must address issues of supply, storage, and transport. Reports on the Beaufort Sea coast suggest that sediment provided by the Mackenzie River exceeds by about a factor of 30 that provided by coastal erosion (Harper and Penland, 1987). This may not be the case for Russian arctic rivers, which supply less sediment and are presently prograding. The following is a list of the types of data required to develop an understanding of the flux of materials from land to sea:

Fluvial contributions: water and sediment discharge to the ocean, sediment types and textures (including carbon content), delta morphology and stratigraphy, delta front stability, ice-related and thermal processes at the delta front, sedimentation rates, and sediment dispersal patterns. Coastal evolution: coastal geology and geomorphology (including permafrost and ground ice), erosional processes, quantification of erosion rates and sediment supply, beach and cliff profiles, models of coastal response to thermo-hydrodynamic processes, relative sealevel history. Shelf transport and deposition: bathymetry and morphology, Quaternary and Holocene stratigraphy, sediment distribution, sedimentation rates, transport processes and rates of reworking. Ice regime: ice climate, regional zonation and dynamics, ice scour, ice piling at and near the coast, freezing storms and frazil production, sediment in ice and sediment dispersal by rafting.

### **Proposed Methods**

#### *Rivers and Deltas*

- Mapping delta morphology and vegetation from satellite imagery;
- mapping delta-front stability from air photos and air video;
- mapping suspended sediments and plume dynamics from satellite imagery;
- mapping wave energy dissipation across the delta front using satellite radar;
- acquiring water and sediment discharge data from appropriate agencies;
- high-resolution seismic stratigraphy of Holocene delta deposits;
- electrical stratigraphy and shear wave velocities to determine permafrost morphology in the land to sea transition;

- bathymetry and morphology of submarine delta;
- shallow coring of delta plain and submarine delta sediments;
- sedimentation rate using  $^{137}\text{Cs}$  and other methods;
- and development and application of numerical models for sediment deposition and reworking in an arctic, shallow marine delta setting.

#### *Coastal Evolution*

- Compilation of existing data on coastal geology and erosion rates;
- detailed mapping of coastal morphology from air video and other sources;
- selection of representative sites for monitoring coastal evolution (rates of erosion and deposition);
- documentation of cliff erosion processes from air photos, ground surveys and sampling;
- investigation of beach profile variance and trends in relation to sediment supply from cliffs;
- analysis of existing air photography and satellite imagery for determination of long-term erosion rates;
- analysis of meteorological, tidal, and ice data to assess variables which affect evolution;
- evaluation of wave climate, refraction and dissipation using a combination of in situ measurements, hindcasting and modelling;
- acquisition of thermal stratigraphy and water temperatures to evaluate effects of thermal regime;
- coring plus palynological analysis and dating at appropriate sites to estimate sea level trends;
- and development and application of numerical models for coupled thermal-hydrodynamic sediment transport and deposition.

#### *Shelf Transects*

- Acquisition of historical bathymetry data;
- analysis of historical shoreface adjustments if suitable data is available;
- sidescan surveys and sediment transport monitoring/modelling to assess potential for cross-shore transport;
- high-resolution swath bathymetry along cross shelf transects from coastal sites;
- high-resolution seismic profiling along the same transects;
- and coring transects across shoreface, shelf and slope to determine present-day sedimentation rates.

#### *Ice Zonation and Dynamics (Including Ice Scour and Sediment in Ice)*

- Mapping of ice distribution and zonation from historical data and satellite imagery;
- reconnaissance overflights, air video, and ice surveys in vicinity of coastal monitoring sites in late winter to identify ice pileup and other interactions with the coast;
- monitoring of breakup processes by air, satellite and ground-based studies;
- ice coring transects in late winter to quantify sediment in ice;
- sidescan surveys to record ice scour;
- and analysis of freezing storm frequency and probability of frazil formation and associated shoreface erosion.



## **New Avenues of Research**

Several critical aspects of working in the arctic coastal zone are related to the thermal conditions which differentiate arctic coastal processes from temperate ones. These include the presence of sea-ice and ground-ice. Sea ice obviously plays a major role in defining the oceanographic environment which controls waves and currents as well as the playing a role in sediment disposition through mediation of river mouth breakup, sediment transport by ice, ice push, rideup, etc. The development of techniques for operating in these environments is of paramount importance. Our work in the Beaufort Sea has lead to the adaptation of an amphibious arctic search and rescue vehicle (Arktos Beta) for seismic data collection in shallow arctic seas (Solomon et al., 1992a) It is particularly useful in the coastal zone for work across the land-sea boundary and where water depths are consistently less than 2-3 m.

These conditions also present severe difficulties for conventional acoustic sub-bottom profiling to ascertain shallow, high-resolution stratigraphy. Marine electrical resistivity systems can be used to some extent for this purpose, but has its limitations (Solomon et al. 1992 a,b; Scott and English, 1994, Sellmann et al., 1989). Other options for surveying in the shallow coastal zone are currently under investigation. One with exciting potential is the use of shear wave reflection and refraction studies. Shear waves would eliminate the shallow water multiple problems and could penetrate gassy sections which are known to be common in the Canadian Beaufort Sea and are likely to be found in other areas of the arctic (especially in the vicinity of deltas).

Arctic coastal evolution is dramatically affected by the presence of ground ice in the form of interstitial, massive and wedge ice. The role of ground ice in terrestrial instability is unquestioned, whereas the potential for it mediation of nearshore profile adjustment is still under debate. Under the auspices of the Geological Survey of Canada, a program to develop a numerical model for coupled thermal-hydrodynamic coastal evolution has just been initiated and a concurrent physical modelling effort has been proposed (Baird and Associates, 1994).

Coring in the coastal zone is also highly impacted by the presence of ground ice. Ground temperatures in the coastal zone are often isothermal at or just below the freezing. Techniques for acquiring cores in their undisturbed thermal state have been refined by the GSC (e.g.Dallimore,1991). Undisturbed cores are essential for determining thermal properties for modelling purposes and understanding transport of energy (heat) and materials (e.g. salt) across the land-sea interface.

A final item of importance is the development of models for sediment resuspension across the shelf. This is critical for developing a complete understanding of sediment (and carbon) budget for the arctic. There is some evidence that surficial muds in the nearshore of the Beaufort Sea are overconsolidated and may therefore be somewhat resistant to erosion (Christian and Morgenstern, 1986). Davidson (1988) also alludes to the uncertainty in the application of sediment transport models in the Beaufort due to the difficulty in determining the critical stresses for erosion and deposition. Refined techniques for ascertaining these stresses using in situ flumes have been developed by the GSC (Sea Carousel, see Amos et al, 1992).

## PECHORA-PALEO ENVIRONMENT AND CLIMATE HISTORY OF THE RUSSIAN ARCTIC

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PECHORA is a Russian-Norwegian interdisciplinary project aiming to reconstruct the history of late Quaternary environment and Early Man in North-Russia.

### Objectives

The main purpose of this project is to increase our understanding of the climatic changes and influence on the physical and biological environment and human habitation:

- 1) Geology and geophysics: Timing and extension of the great ice sheets and crustal movements.
- 2) Paleobotany: Vegetation history.
- 3) Archaeology: Immigration of Early Man and cultural development.
- 4) Paleozoology: Migratory pathways and changes in the mammalian fauna.

We will especial focus on the last interglacial-glacial cycle, a period of 130,000 years. However, we also consider to study older periods including the Saale ice age.

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## **Method**

The investigations, which are based on geological and archaeological studies, include a wide range of methods:

- 1) Quaternary stratigraphy and sedimentology based on studies of exposed sediments and cores
- 2) Remote sensing based on air photos and satellite images
- 3) Reconstruction of shoreline displacement and isostatic modelling
- 4) Pollenstratigraphy from lake sediments
- 5) Archaeological excavations of paleolithic sites and comparative studies
- 6) Osteological studies of faunal remains from archaeological and geological sites

## **Investigation Area**

The study area includes the European part of North-Russia that was inundated by the Barents and Kara Ice Sheets. If possible it is also desirable to do field work on Novaya Zemlja and/or Zevernaja Zemlja.

## **Progress and Results**

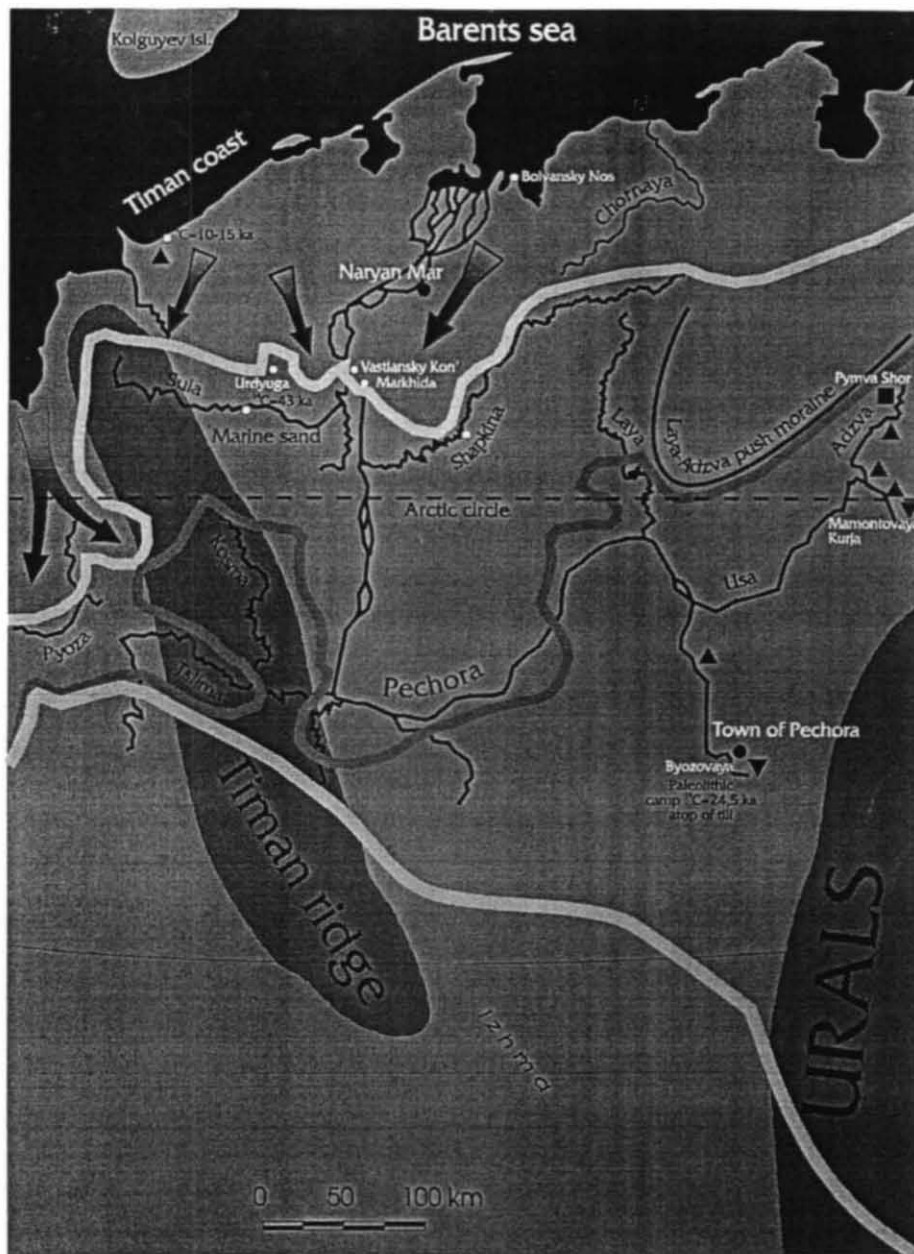
During 1993 and 1994 geological field work have been undertaken in the Pechora region, Arctic Russia. The principal task has been to check some main assumption on the stratigraphic and spatial position of the last glacial maximum. Based on these preliminary investigations we infer that the southern Weichselian ice limit in this region corresponds with a morphological distinct endmoraine zone, the so-called Marchida moraine, running nearly parallel with the Barents Sea coast, some 100-150 km inland. However, the exact age of this end moraine is still an open question.

Preliminary archaeological investigations of two paleolithic sites, Pymva Shor and Mamontovaya Kurja, were also undertaken in 1994. On both sites it has been found remains of a varied mammalian fauna together with Man made artifacts. These sites are the northernmost paleolithic sites so far discovered in Europe and indicate that the Arctic were inhabited much earlier than previously assumed.

It is the intention that more geological and archaeological field work will be done in the next few years.

## **Link to Other International Programmes**

The project is associated with the international project Paleoclimates of Arctic Lakes and Estuaries (PALE), which is a contribution to the project Past Global Changes (PAGES) under the International Geosphere-Biosphere Programme (IGBP)/Global Change. The purpose of PALE is to reconstruct arctic lake and estuarine paleoenvironmental history and paleoecosystems as a basis for understanding how arctic areas respond to, or cause, climate change.



Main Belt of Marginal Landforms (Lavrov 1977)  
Weichsellian ice limit according to our investigations

Late Weichsellian maximum ice limit (Lavrov, 1977)

647

Late Weichsellian ice limit (Lavrov 1987, Grosswald 1991/1994)

## Location map of the Pechora basin

- Marine sand : formations not covered by till
- ➔ : ice flow as inferred from fabric, striae and push moraines
- : Pymva Shor, Paleolithic cave
- ▲ : Mesolithic site
- ▼ : Paleolithic site

## PREDICTING SEDIMENT DELIVERY AND STRATIGRAPHY ON THE RUSSIAN ARCTIC SHELVES

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Russian rivers that flow into the Arctic Ocean drain vast lowlands and upland areas, unlike many other of the world's large rivers that have headwaters in medium to high mountains. As a consequence, the truly large Russian Rivers, the Ob, Lena and Yenisey Rivers, each with over two million square kilometres of drainage basin, carry relatively clean water in terms of average suspended concentration. Exceptions to this generalization include the Indigirka and Yana Rivers that have significantly higher suspended concentrations. The Russian arctic rivers do carry significant quantities of sediment to the arctic ocean because of their very large discharges.

	Suspended Load (kg/s)	Discharge (m <sup>3</sup> /s)	Concentration (kg/m <sup>3</sup> )	Drainage Area (10 <sup>6</sup> km <sup>2</sup> )	Runoff (mm/a)
Upland (500-1000m)					
Indigirka	440	1710	0.26	0.36	150
Pechora	193	3370	0.06	0.25	425
Ob	507	10300	0.05	2.5	130
Lena	380	16200	0.02	2.5	205
Yenisey	412	18000	0.02	2.6	220
Lowland(100-500m)					
Yana	95	910	0.10	0.22	130
Severnay	143	3660	0.04	0.35	330
Kolyma	190	2840	0.07	0.64	140

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data after: Milliman, J.D. and Syvitski, J.P.M. 1992. Geomorphic/tectonic control of sediment discharge to the ocean: The importance of small mountainous rivers. *Journal of Geology*, **100**, 525-544. Mulder, T. and Syvitski, J.P.M. (submitted). Occurrence and frequency of hyperpycnal river discharge to the world's oceans. *Journal of Geology*.

Together Russian arctic rivers deliver over 80 Mt/a of sediment to the arctic shelves (or about 0.05 km<sup>3</sup>/a). These are modern rates, based on modern climate, modern ground vegetation, modern permafrost conditions, and modern glacial conditions or lack thereof. If these averaged values remained constant for the Holocene period, then 500 km<sup>3</sup> of material was delivered to the Russian shelves over the last 10,000 years. Can this Holocene fluvial material be accounted for? Can the distribution this Holocene sediment on the Russian shelves be predicted with knowledge of modern oceanographic and fluvial conditions and Holocene sea level conditions?

Continental margins are dynamic features evolving in response to sediment delivery and sediment redistribution by gravitational and oceanographic forces. This proposal seeks to apply GSC's SEDFLUX numerical models to Russian Arctic margins. SEDFLUX models are useful for the simulation of sediment delivery and accumulation on continental margins over time scales of



tens to thousands of years. The models will be used to predict the evolution of the continental margin offshore of major Russian rivers including the changing offshore lithology as a function of sea level, terrestrial sediment delivery, and other relevant climatic and oceanographic factors. The models will be capable of simulating the seismo-acoustic features at a scale directly comparable with very-high resolution seismic records and geotechnical properties observed on cores. These models are presently undergoing marked improvements as part of ONR's STRATAFORM project lead by Chuck Nittrouer and Joe Kravitz. I am one of the group leaders within that project.

### **Previous Work**

This work effort hinges on the use and refinements of existing SEDFLUX numerical models. These models are capable of making daily predictions of sediment transport and deposition over periods of 10's to 100,000's of years, tracking sediment size and bulk density on a continental margin. Semi-independent basin-scale ANSI standard Fortran models, RIVER, DELTA, GRAIN and FACIES (respectively: Syvitski and Alcott, 1994; Syvitski and Daughney, 1992; Syvitski and Alcott, 1993; Alcott & Syvitski in prep.) will be employed to simulate a river discharge carrying a multi-sized sediment load onto and across a continental margin. RIVER3 uses a 1-D linear deterministic-stochastic approach to model daily river velocity and channel dimensions at a river mouth, and the transport of five sediment size fractions. DELTA6 (Syvitski and Alcott, 1993b) combines this discharge data with characteristics of a continental margin to simulate the varied sediment transport pathways within a stratified water column. DELTA6 predicts the time-dependent seafloor surface and the accumulation rates produced by each depositional mechanism (bedload dumping at the river mouth, transport and deposition of turbidity currents generated near a delta front, sedimentation under buoyant river plumes, current and wave erosion and transport, debris flows generated from slope instabilities). GRAIN3 uses fluvial information from RIVER, river mouth position and turbidite tracking of DELTA to predict the interannual grain size properties of the seafloor. FACIES1 supplies the resultant lithostratigraphic properties (grain size and bulk density) of the continental margin based on simulated outputs of DELTA.

The first use of these models for the global change initiative was when the effect of sea level rise on deltaic environments was investigated (Syvitski, 1992a). At about the same time the role of carbon content in Baffin fjords was being investigated by these SEDFLUX models as a proxy to sediment accumulation rates and thus to river discharge, ice melt and thus climate (Syvitski et al., 1990; Syvitski, 1992b; Williams et al., in press). Andrews and Syvitski (1994) applied these models to examine the delivery of sediment onto Canadian and Greenland arctic continental shelves.

More recently, the SEDFLUX models were applied to two future contrasting climate change scenarios for the eastern Canadian Arctic (ECA), i.e. warmer summers or warmer and moister winters (Syvitski and Andrews, 1994). Both climate scenarios result in an increased sediment flux over the next 200 years until a new steady state was reached. However warmer summers will have the largest impact by: (1) melting ice caps, (2) inducing more expansive and turbid river plumes, (3) increasing progradation of the coastline into the sea, (4) raising relative sea level, and by (5) increasing the number and size of turbidity currents generated off river mouths. Warmer and moister winters that may lead to deviations from these impacts include: (1) growth of ice caps, (2) falling relative sea level, (3) stability of coastlines as increased

sediment delivery keeps pace with changes in regional relative sea level; and (4) fewer turbidity currents as more of the bedload is trapped on top of the sandur surfaces. RIVER4 is now being tested, capable of: 1) including direct input from GCM output (monthly averages and standard deviations of temperature, rainfall, snowfall and evaporation for example); 2) tracking decadal variations in precipitation or temperature drift and variability and this effect on ice sheet ELA (growth or ablation); and 3) a better way of handling rare flood events brought on by centennial or longer climate events.

## **Proposal**

### **1. Shelf Delivery Model**

Sediment input plays an important role in the dynamics of continental margins. It is important to recognize seasonal sources such as river flooding, climate trends, random catastrophic events, and the effects that fluctuating sea-levels can have on sources. A sediment delivery model will be to the Russian continental shelf that is capable of simulation of fluvial input from a point source onto continental margins. The model will be used to help provide information on sediment dynamics to stratigraphers who gather their information from cores and seismics, to help constrain their interpretation on steady-state vs. catastrophic events.

### **2. Litho- and acoustic-stratigraphic model**

A crucial element to understanding slope stratigraphic sequences in time and space is the delineation of stratal geometries, lateral and vertical variability, and three-dimensional geometry of the discrete depositional units (i.e. their lateral continuity, geometry of bounding surfaces, vertical and lateral facies relationships, and internal variations in physical properties). A multi-process slope sedimentation model will be applied to the Russian continental shelf to help understand how external forcing mechanisms affect the events that control the seafloor morphology and stratigraphy. The final model will be capable of generating synthetic seismic sections at the vertical resolution of a very-high resolution Chirp or Huntex profiler.

The proposed modelling effort will require very-high resolution seismic information to be acquired to compare with model outputs and to provide time horizons upon which sediment will accumulate numerically. The proposal also requires oceanographic models to be acquired by other project proponents and linked to SEDFLUX models. The proposal requires that other project proponents acquire appropriate cores and conduct high-resolution core analysis for sediment properties. The model can also be adapted for use by those wishing to trace the pathways and accumulation of organic carbon and river-borne pollutants. The proposal costs are in the neighborhood of \$75K per year for three to five years, depending on the resolution of the models predictive capabilities.

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## SHALLOW ICE CORE RECORDS FROM FRANZ JOSEF LAND, RUSSIA: PRELIMINARY RESULTS AND FUTURE PLANS

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An international cooperative field expedition to Franz Josef Land in the Russian High Arctic to recover shallow ice cores and to complete radio echo sounding of all of the major ice masses was accomplished in Spring, 1994. The 11-member expedition team consisted of researchers from the Byrd Polar Research Center at The Ohio State University, the Scott Polar Research Institute at the University of Cambridge, U.K., and the Institute of Geography at the Russian Academy of Sciences, Moscow. Four ice caps within Franz Josef Land, including a west to east transect across the southern half of the archipelago (Figure 1), were drilled and the frozen cores were successfully returned to the cold room at Ohio State. The longest of the cores, 24.07 m, was drilled on the summit of Windy Dome on Graham Bell Island (80°57' N, 63°33' E, 580 m elevation) in the southeastern portion of the archipelago. Because of decreasing air temperatures from west to east, and increasing precipitation from NW to SE, this ice cap has the best potential for containing a well-preserved record of past climate.

Borehole temperature profiles at the four sites indicate a strong gradient from east and west, and differences in elevation among the ice caps is a major influence on the seasonal accumulation/melting cycle exhibited. For example, the 10 m temperature on Luna Dome, Alexander Land (elevation 375 m) in the far west is -3.3°C, whereas the summit of Graham Bell (200 m higher) reads -6.7°C at 10 m. This is a much larger difference than would be expected from the lapse rate alone. Also, the summit of Hydrographer Dome (Heiss Island), which lies at a low elevation of 242 m, is not currently in an accumulation zone, but rather is ablating year after year. This is inferred by the mere 50 cm of fresh snow/firn at the top, underlain by a large dirt layer covering solid ice below. Roughly 4 m of featureless ice was drilled below the dirt layer, and it is our belief that this is "old" ice that cannot be dated, and that the particulate matter continues to accrete on the upper ice surface each summer as the ablation continues. The current conditions of Hydrographer Dome are consistent with the findings on other small ice caps, such as Victoria Island between Franz Josef Land and Svalbard (Govorukha, 1988).

Core 1 from Graham Bell Island has been analyzed for anion chemistry, particulate concentration and size distributions,  $\delta^{18}O$ , and beta radioactivity (Figure 2). Early results suggest an accumulation of 400-700 mm water equivalent over the past 15 years, with a decreasing trend towards the present. Mean concentrations of  $Cl^-$ ,  $SO_4^{2-}$ , and  $NO_3^-$  are 730 ppb, 495 ppb, and 100 ppb, respectively, with an extremely large seasonal signal which is likely related to regional sea ice extent and/or oceanic biogenic activity. The mean  $\delta^{18}O$  value is -16.9‰, and shows no distinct seasonality, possibly an effect of sublimation enrichment and/or meltwater percolation effects. Particulate profiles indicate an increase in dust deposition, along with an increasing fining, over the past 20-25 years, which is anti-correlated with decreasing trends in both  $Cl^-$  and the occurrence of large superimposed-ice layers.



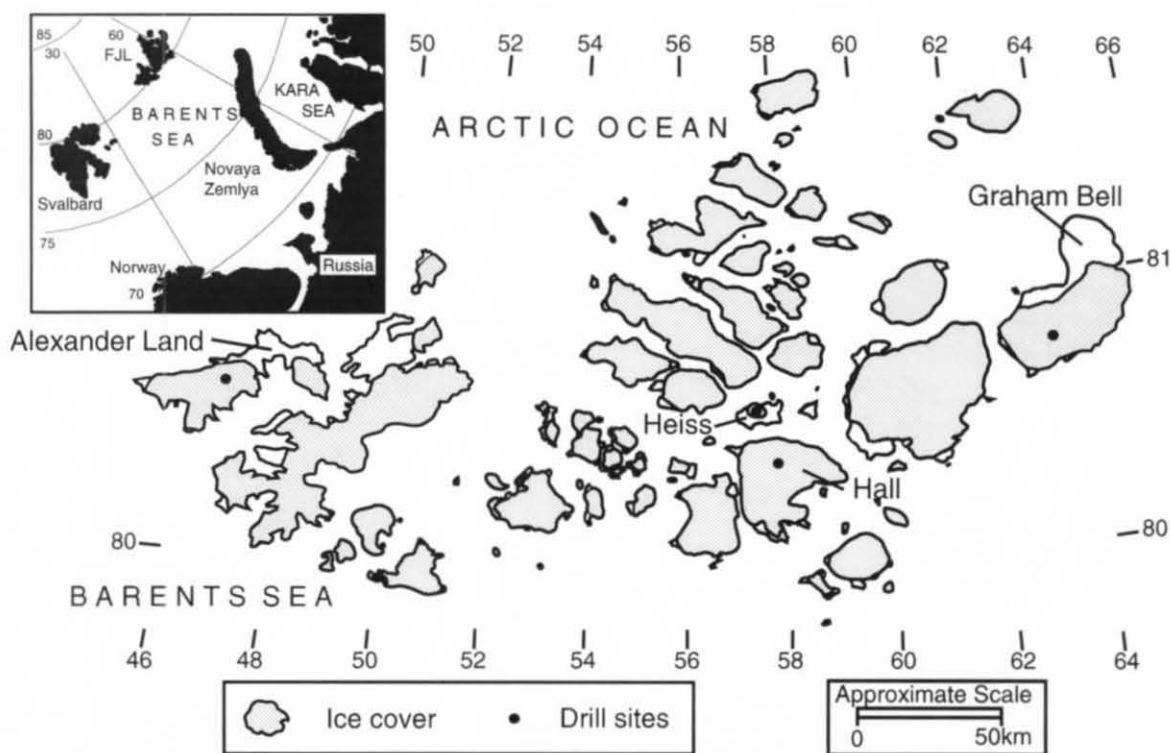


Fig. 1 Map of Franz Josef Land with drill site locations

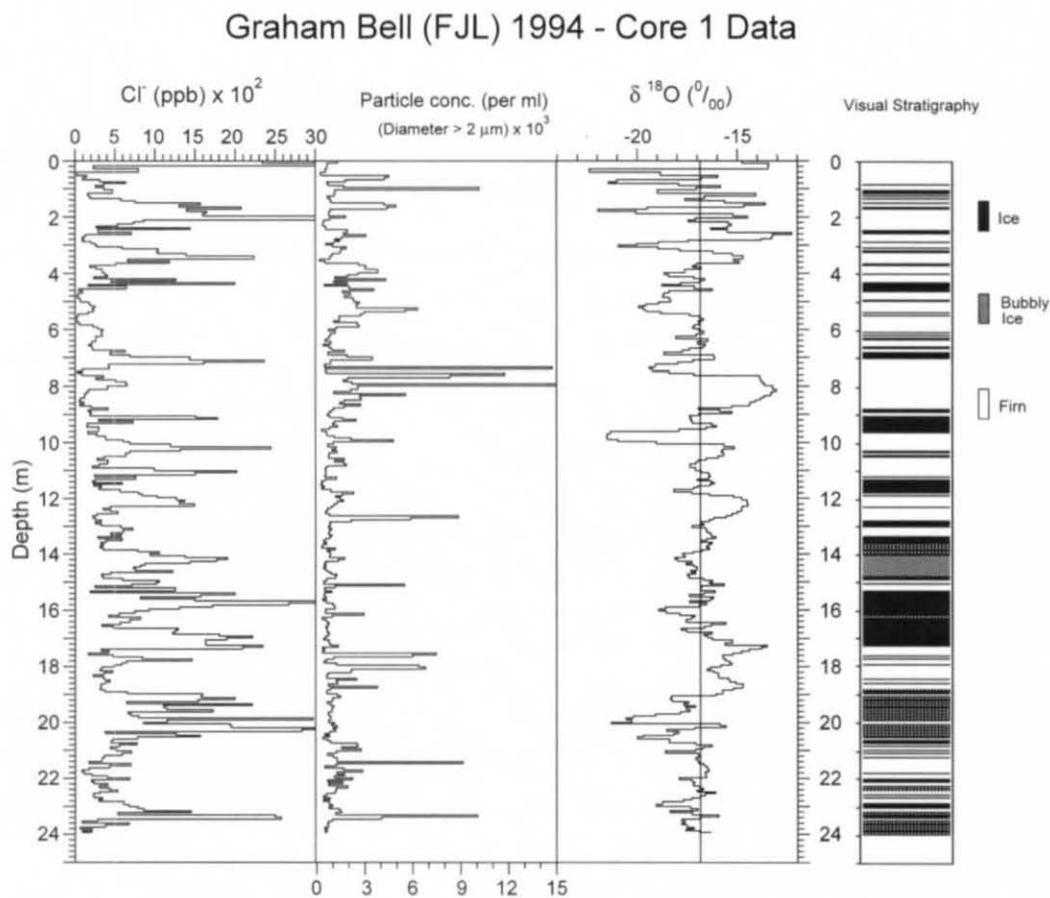


Fig. 2 Chloride, microparticle concentration, oxygen isotopes and stratigraphy plotted with depth for Graham Bell (FJL) 1994-Core 1.

The 1994 field program was primarily a reconnaissance mission to determine the quality and length of the climate records, and to set up the logistics and international cooperation necessary for a possible future deep-drilling effort on Graham Bell Island. Of paramount importance for developing a high quality record is the establishment of an accurate time scale. In Graham Bell Core 2, because an annual signal is not present in either the isotope or particulate records, and because the occurrence of meltwater-ice layers is highly variable, dating of the core has been based on anion chemistry alone. Although in a large portion of the core (especially where there is a high percentage of firn) the chloride peaks are distinct and nearly uniformly spaced, the presence of several large meltwater-ice layers in the bottom part of the core has obscured the seasonal signal and created uncertainty in the dating.

However, the seasonality in the total record from Graham Bell may not be obscured by persistent meltwater-ice layers, as preservation of the signal in past periods (eg. the Little Ice Age) is likely to have been enhanced relative to the present negative-balance condition. Supporting this are finds from glaciological field studies on Hooker Island (Grosswald and Krenke, 1961) and Alexander Land (Sinkevich, et al., 1991) of negative or zero borehole temperature gradients ( $-0.6^{\circ}\text{C}$  in Alexander Land from 20 to 54 m depth), indicating the general increase of meltwater within the snow pack towards the present. Koerner (1977) measured the meltwater distribution in ice cores from Devon Island, Canada. He found that the amount of ice in each annual layer in the firn was correlated with the amount of open water in the channels between the Canadian Arctic Islands, for the 14 years for which detailed sea-ice records were available. The possibility then exists for the development of a sea ice proxy record in this manner for the northern Barents Sea from a Graham Bell ice core. In addition, the extreme range and apparent sensitivity of the ice core parameters (eg. chloride) even in the short time span developed in these shallow cores, suggests that the mean values and seasonal oscillation would be very indicative of past climatic fluctuations. Therefore, the changes in record quality over time may in fact be a climate record in itself.

The potential of a very long record being produced from a core drilled to bedrock on Graham Bell is quite high. Although work by Forman, et al., (1992) suggest that glaciers in Franz Josef Land may have receded behind their present margins prior to 8000 yr BP, there is no evidence to suggest that ice caps in this area were completely absent at any time since the last glacial. The estimated ice thickness at the center of Windy Dome of 450 m (J. Dowdeswell, personal communication) with a present-day accumulation rate of 400-700 mm water equivalent would also tend to support the likelihood of a long record.

The significance of an ice core paleoclimate record from the Russian Arctic should be quite clear. A majority of the ice coring work in the Arctic region has been accomplished and in Greenland and the Canadian Arctic, and obtaining a data set from Franz Josef Land would contribute to circum-polar coverage. This record could potentially provide information useful for tackling difficult problems such as the stability of the Eemian, and changes in sea ice concentration and the influx of North Atlantic waters into the Barents Sea during the Holocene.

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## PRESENT DYNAMICS OF WATER AND ICE AND THERMOHALINE PROCESSES IN THE ARCTIC SEAS

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### **Thermohaline water structure and dynamics**

#### *Background*

On the basis of a large number of observations there are obtained maps of the distribution of mean multiyear water temperatures and salinities at different levels, as well as the distribution of such chemical water properties as pH, oxygen, phosphate and silicon values. The diagrams of water and ice circulation have been constructed (Atlas, 1980;1985). The water circulation variability is found to be dependent on the prevailing type of atmospheric circulation. An analysis of the variability of thermohaline characteristics has allowed one to delineate the most frequent types of the distribution of thermohaline water characteristics, areals of spreading of river, Atlantic and Pacific waters in the Arctic seas. And similarly to the water circulation character the most large-scale changes in the water medium state turned out to be related with two different types of the atmospheric pressure fields: at the prevailing influence of the Arctic High and the prevailing influence of the Icelandic Low ( Nikiforov and Shpaikher, 1980).

The directions and intensity of the main flows of river water transport and their effect on the hydrological regime of the seas are found out. The observation data show a relationship between the zones of river water spreading and the areas of enhanced concentration of iron and manganese in bottom sediments. This can be attributed to the coagulation of colloidal-chemical solutions and suspended substances in the areas of river and sea water interaction and their sedimentation.

The relationship between the vertical and horizontal distributions of fluorescence intensity and thermohaline characteristics and between the hydrochemical and hydrobiological ameters has been found out. A conclusion about a significant interannual variability of hydrochemical parameters at the preservation of main typical features of the hydrochemical structure of the Arctic Seas at present has been made and the main causes of this variability identified.

The estimates of the wave intensity for ice-free sea regions have been obtained. The natural typical features of surge and tidal level oscillations of the Arctic seas predominantly for the coastal zone are found out. The statistical and hydrodynamic methods for level and wave forecast have been created (Baskakov, 1991) To calculate the currents both on the whole for the Arctic Ocean and for the Arctic Seas there are constructed the hydrodynamical methods which describe sufficiently well general water circulation features (Kulakov and Pavlov, 1988).

The estimates of sedimentation of suspended substances in the Siberian shelf seas are obtained. It is believed that with the destruction of the shores the input of suspended substances is from 25 to 50% of the total solid river outflow. The input of solid mineral material to the sea from the ice surface at its melting is slightly less. General evidence on the granulometric composition of suspended substances has been obtained (Belov, 1990).

## Problems

The following phenomena have been insufficiently studied:

- currents, upwellings and downwellings of the coastal zone in various seasons of the year;
- processes of an active dynamic and thermal interaction of the sea with shores, islands and shallow regions;
- hydrological, geochemical, geomorphological and biological processes in the coastal zone, river mouth areas and in the shallow regions of the Arctic Seas;
- and evolution of the shelf and coastal regions of the sea as a habitat of flora and fauna and as regions of active human activity.

## Phase Transitions and Ice Dynamics

### *Background*

The observation data on the ice drift are generalized and presented as the circulation charts (Atlas, 1980; 1985). The theory of the ice cover drift and the mathematical methods for calculating the wind-driven drift of the ice cover of different concentration have been developed (Timokhov and Kheisin, 1987).

The observation data on the onset of ice formation, fast ice stable formation, onset of ice melt and ice concentration change in the Siberian shelf seas are generalized.

A large variability of the ice mass in the Arctic seas, ice cover state, including its concentration, formation of extensive polynyas, hummocking, contamination, etc. has been found out (Izd, 1970). The observations are generalized and statistical models of hummocks, morphometric characteristics of stamukhas, dimensions of the ice floe, composing the ice cover in different seasons, etc. are suggested (Timokhov and Kheisin, 1987; Borodachev, et al. 1990).

The models of the sea ice cover as a shipping medium and the models of joint water and ice dynamics have been constructed. The methods of the forecast of ice phases and ice distribution in the Siberian shelf seas are developed (Appel, et al., 1991).

The studies of the changes in sea ice distribution and biological productivity have been made (Abramov, 1994)

## Problems

The following phenomena have been insufficiently studied:

- processes of phase transitions, mechanisms of the freezing of suspended substances into ice at ice growth and migration of inclusions in the ice thickness; influence of inclusions on optical, thermophysical, radiophysical properties of ice and the process of its melting;
- mechanical, thermodynamic and phase interaction of ice with the material, composing the sea shores and bottom;
- thermodynamic cycles, structural ice cover transitions and associated interaction cycles with the atmosphere and the ocean, cycles of geochemical processes and life cycles of bacteria and biota.

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## **MONITORING CHANGE IN ARCTIC TERRESTRIAL ECOSYSTEMS AT MULTIPLE SCALES**

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Accurate assessment of potential change to arctic ecosystems and their contribution to global carbon and trace-gas budgets requires a systematic method to monitor vegetation, soils, and permafrost. It also requires a better understanding of the characteristics and distribution of arctic vegetation. Ideally, it would be desirable to establish a circumpolar network of sites where a standard set of measurements are made and to set these observations within a common framework of a global vegetation database. This abstract describes a GIS framework that is being developed in Alaska and two ongoing projects that involve Russian scientists in these overall goals.

### **Kuparuk River Basin as a Model for Other Studies of Arctic Land-Ocean Interactions**

The idea for a circumpolar network of sites originated with a hierarchic geographic information system (GIS) that is being made for the Arctic System Science (ARCSS) Land-Atmosphere-Ice Interactions (LAI) Flux Study. The goals of the Flux Study are to (1) develop a quantitative understanding of the variables and processes controlling the fluxes of trace gases, water and energy from arctic ecosystems to the atmosphere and ocean, and (2) to determine how these fluxes will change in response to future variations in climate (Weller et al. 1995 in press). Doug Kane and Larry Hinzman at the University of Alaska are developing a hierarchy of surface runoff models for the basin, and John Hobbies group at the Ecosystem Center are measuring the flux of organic carbon and nutrients to the streams and ultimately to the ocean. Much of the study relies on a GIS and remotely-sensed information for the spatial modeling of hydrological, pedological and biological characteristics. The GIS project will produce maps of variables important to other investigations within the Flux Study and will provide (1) georeferenced data for the development of satellite-based algorithms, and (2) fields of surface information as boundary conditions required by grid-point models.

An existing GIS (Fig. 1, Walker and Walker 1991) is being expanded to accomodate new sites for the Flux Study. The hierarchic structure of the GIS provides a geographic framework for the plot-, landscape-, and regional-level investigations. Databases are being constructed at five scales (1:10, 1:500, 1:5000, 1:25,000, and 1:250,000) for several nested sites within the 8,100 km<sup>2</sup> Kuparuk River drainage on the Alaskan North Slope. Geobotanical variables are mapped as part of integrated terrain databases and include vegetation, soils, glacial geology, surficial geology, surfical geomorphology, and percent water cover. Other elements of the GIS database include or will include digital terrain models, maps of surface

reflectance, soil moisture status, indices derived from remotely sensed data [e.g. greenness index, wetness index, and the normalized difference vegetation index (NDVI)], soil carbon data, and maps of regional biophysical properties important for models of land-atmosphere interactions such as leaf area index (LAI), biomass, and intercepted photosynthetically active radiation (IPAR). Standard methods will aid in the development of consistent legends and GIS techniques that can be applied to comparative studies of other arctic regions. On the North Slope of Alaska, we have constructed hierarchic databases at Toolik Lake and Imnavait Creek, and we propose building additional databases at Happy Valley, Prudhoe Bay, and Barrow.

### **Network of Grids to Monitor Status and Changes to Arctic Vegetation, Soils, Snow, and Permafrost**

Part of the hierarchic GIS scheme, is a 1 x 1-km grid that is established at each of the sites. The first grid was surveyed at Imnavait Creek in 1987 by Carl Benson as part of the Department of Energy, R4D project. So far, we have established six grids on the North Slope, one on the Gydan Peninsula, Russia, and two in the Colorado alpine. The purpose of the grids is to develop a georeferenced database of numerous easily measured geobotanical parameters and periodically monitor changes to these variables (Table 1).

The grids are accurately surveyed and labeled according to a UTM coordinate system. The grid points are spaced 100-m apart and marked with 1.2-m PVC stakes. The stakes are highly visible and permit monitoring of the sites during winter and in adverse weather conditions. So far, large geobotanical datasets have been collected at Niwot Ridge, Colorado, Toolik Lake, Imnavait Creek, Barrow, and the Lake Parisento, Russia. During the workshop a summary of the data sets from each site will be presented. Vegetation characteristics are being monitored with permanently marked point quadrats (Walker and Walker, 1991). The method allows us to monitor changes to the overstory and understory and the height of the vegetation canopy. Depth of the organic soil horizons are measured and several soil physical and chemical properties are measured at 10-cm depth (pH, organic matter, particle size, nutrient concentrations). Numerous site factors are also recorded including, rockiness water depth, terrain age, surficial geology, surficial geomorphology, and water depth. At minimum, depth of the active layer is measured once at the end of the summer. At some sites data are collected throughout the summer. Similarly, snow is measured at all grids just prior to melt, but some grids have more frequent observations (Hinzman et al). Several of the grids also have permanent soil temperature monitoring probes that continuously measure temperatures at every 10-cm in the active layer and upper part of the permafrost table (Nelson et al.). At two of the sites, there are ongoing snow-fence experiments to monitor the effects of altered snow regimes and temperatures as part of the International Tundra Experiment (Moleau et al.). Additionally, several of the sites have very detailed geobotanical and orthophoto topographic maps at 1:500 scale, digital terrain models, and SPOT HRV/XS remotely-sensed data.

### **Pan-Arctic Vegetation Map**

Many ongoing ecosystem research, monitoring programs, and potential studies of arctic land-ocean interactions would benefit by a vegetation map that displays a modern understanding of arctic vegetation and which could be easily interfaced with remote sensing, GIS, general circulation models, and regional ecosystem modeling efforts. The boundaries on existing coarse-scale maps of the Arctic are very general and of marginal use for global GIS databases. A recent workshop in St. Petersburg, Russia established a group of international collaborators, who

agreed to develop a new vegetation map of the circumpolar region (Walker et al., in press). The new vegetation map will be tied to global satellite-derived spatial databases and digital terrain models. One of the products of the project will be a false-color mosaic of cloud-free composited false-color images from the Advanced Very High Resolution Radiometer (AVHRR) aboard the NOAA satellites (1.1-km pixel resolution). The image will be a polar projection of the terrain north of 50° latitude, and will be used as a base for vegetation mapping of the region north of the arctic treeline. The first map products will utilize a Lambert azimuthal equal-area projection of the circumpolar region at a scale of 1:7,500,000. Also, a map of the normalized difference vegetation index (NDVI) will be prepared from the same data set as the base map for the vegetation-type map. The map will display the maximum NDVI value during the growing season for each pixel. The U.S. Geological Survey Earth Resources Observation System (EROS) Field Office in Anchorage, Alaska, will prepare both remote-sensing products as color hard-copy maps and in digital form on a CD-ROM. The most difficult part of the project will be a 1:7,500,000 synthesis map that will be derived from existing vegetation maps and aerial photo interpretation. False-color AVHRR satellite image will be used as base imager to make the map. This final step will likely take several years. Collaborators are meeting in Arendal, Norway in 1995 to begin work on the legends. The project is compatible with the US-Canada ecoregion mapping program and the circumpolar permafrost mapping projects. This project is closely tied to a parallel effort to develop a circumpolar arctic vegetation database (Walker et al. 1994).

## ARCHAEOLOGICAL RESEARCH IN NORTHEASTERN SIBERIA

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### Current Research

My current research centers around the Diring Yuriak site in the Lena Basin of central Siberia. The Diring site is located about 140 km south of Yakutsk on the highest terrace of the Lena River (61° 12' N Latitude; 128° 28' E Longitude). Here, over 4000 artifacts (mostly unifacial pebble choppers, flake-and-core tools, anvils, hammerstones, and debitage made of quartzite), have been recovered by Academician Yuri Mochanov (1992, 1993) from activity areas in a 26,000 m<sup>2</sup> excavation area. The specimens from Diring are true human-made artifacts and are not geofacts. Russian scientists have reported that the Diring site is about 2 million years old based on a paleomagnetic reversal stratigraphy and three radiothermoluminescence ages. Academician Mochanov has proposed that the Diring site demonstrates that pre-modern humans were present in Siberia and that these people were able to survive and evolve in the rigorous arctic environment.

During the summer of 1993, I conducted geoarchaeological investigations at the Diring site. I examined the stratigraphy and sediments at the site, and collected samples for sedimentological and geochronological analysis. These studies were undertaken to evaluate the stratigraphy and age of the Diring site.

At the Diring site, I recognize twelve major Quaternary age stratigraphic units (Fig. 1). These unconsolidated sediments unconformably overly Cambrian age limestone designated unit 1. Above this unconformity occur alluvial sand and gravel deposits (units 2 and 3) and sand wedge fillings (unit 4). Units 3 and 4 are truncated and a gravel lag has formed on this surface (unit 5). The artifacts at Diring were made from the cobbles on this deflation surface. This gravel lag is in turn overlain by eolian sand (units 6, 7, and 8) and loess (units 9 and 13) deposits which are cryoturbated. A major unconformity separates these units from the next overlying units. Unconformably overlying the older units are units 14, 15, and 16. These are eolian sands that have a dune morphology and drape onto the older eolian units.

Thermoluminescence age estimates generated by Dr. Steve Forman at Ohio State University provide age control for the stratigraphy. Two thermoluminescence samples from units 4 and 6, bracketing the cultural horizon, yielded ages of around 400,000 B.P. Another sediment sample from unit 13 yielded an age of around 250,000 B.P. Two samples from units 14 and 16 both produced ages of around 20,000 B.P.

With these results, the following geological history of the Diring site is proposed. Sometime prior to 400,000 B.P., the Lena River scoured the limestone bedrock underlying the Diring site. During this erosional period the gravel and sands of units 2 and 3 were deposited. Sometime after this episode of deposition, the river downcut and abandoned its former stream bed. Starting about 400,000 years ago, the alluvium at Diring became frozen and sand wedges were created (unit 4). Following this cold period, the ground thawed and deflation occurred creating the gravel lag (unit 5). After the lag was created, people came onto the site and utilized the lithic material to make tools. Shortly, thereafter, eolian sands drifted over the site and covered the gravel lag surface creating unit 6. More eolian sand and loess deposition followed



(units 7, 8, and 9) with loess (unit 13) finally deposited around 250,000 years ago. Deposition ceased at Diring from roughly 250,000 B.P. to 20,000 B.P. During this time, the lag surface was reexposed toward the front of the terrace as the overlying deposits were eroded. Starting around 20,000 B.P. eolian deposition began again at Diring and created units 14, 15, and 16 which cover the reexposed deflation surface and drape onto the older eolian sediments.

The thermoluminescence age estimates indicate that at a minimum, the archaeological material from the Diring site is older than 250,000 years old. This is the oldest reliable finite thermoluminescence age from the stratigraphic section and even it is from unit 13 which lies 4 m above the cultural horizon. If the two thermoluminescence ages from units 6 and 4 that bracket the occupation surface are correct, they would indicate that the site is approximately 400,000 years old. However, these ages are very close to the maximum limit of the thermoluminescence technique and may not be accurate. Indeed, a second sample from unit 6 could not be dated by the thermoluminescence method because all the electron traps within the sediment grains were filled. This may suggest that the cultural layer is older than 400,000 years. All that can presently be said about the thermoluminescence results is that the site is definitely older than 250,000 yr B.P. and may be 400,000 or more years old.

The thermoluminescence ages confirm that the Diring site is the oldest site known in central Siberia and that early humans were living in Siberia a quarter to a half million years ago. Mochanov's discovery is extremely significant and opens a new chapter in the Paleolithic prehistory of the Old World. Diring will force archaeologists to reevaluate their ideas about the movement of early humans and their ability to adapt to cold climates. In addition, the Diring site has implications for a potentially early migration of people to the Americas.

### **Research Priorities**

There are many archaeological research questions that need addressing, especially given the new time depth of human occupation in Siberia based on the evidence from the Diring site. The most significant questions include:

- 1) The excavation of a habitation site from the Diring time period. The Diring site appears to be primarily a lithic workshop. Somewhere in the region there must be habitation sites. Rockshelters above the terrace on which Diring rests should be investigated for evidence of early habitation. Numerous shelters are known from the Lena-Pilar region.
- 2) What is the geographic distribution of the early Paleolithic material in Siberia? What is needed are archaeological surveys of major river valleys to locate additional sites that are the same age as Diring. Much of the Lena River has been examined and twelve additional Diring-age sites have been located by Mochanov. However, we need to know how far these sites extend to the north and east. This has significant implications to the timing of the entry of people into the Americas.
- 3) What is the archaeological record for the period from 500,000 to 35,000 B.P.? What is the prehistory of Siberia during the rest of the early Paleolithic and middle Paleolithic? Again, survey followed by later excavation may shed light on whether the region was abandoned or continuously occupied. Survey should be undertaken of various river valleys to determine the age of the geological terraces.
- 4) Examination of the late Paleolithic Diuktai Culture (35,000 to 10,000 B.P.). All dated Diuktai sites should be reexamined. These sites excavated by Mochanov should be revisited and new radiocarbon samples collected. In addition the artifact collections from these sites should be examined, especially the early material dating from 35,000 to 20,000 B.P.

5) What is the archaeological record of river valleys in the far northeastern section of Siberia? This is the area through which people would have passed on their way to North America during the Pleistocene. Thus, the alluvial and eolian deposits in these valleys, as well as rockshelters, should be examined for evidence of early human migration. These data are crucial to understanding when people migrated to North America.

All of this research should be undertaken in cooperation with Russian scientists in this region.

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## WEATHERING AND MATERIAL TRANSPORT IN THE ANADYR RIVER- ESTUARINE SYSTEM

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We have recently initiated a research project on the Anadyr river-estuarine system of Northeastern Russia. This research is sponsored by the Office of Naval Research (as part of the Arctic Radionuclide Program) and NSF Ocean Science Division. The objectives of this research are: 1) To assess the concentrations of radionuclides, characteristically associated with fission processes, in sediment samples from the major tributaries of the Anadyr River (ONR, Clark Alexander, PI). 2) To obtain a better understanding of products resulting from arctic-subarctic weathering, the fate of these materials ( primarily trace elements) in the freshwater- seawater mixing zone and the relative contribution of fluxes to the ocean from smaller rivers of this morphoclimatic zone (NSF).

### Background

Most of the past studies of arctic-subarctic rivers have focused on major element chemistry and have provided a reasonable understanding of weathering in high latitude watersheds such as those of the Yukon and MacKenzie, in North America, and the Ob, Lena and Yenesei in Russia (Reeder et al., 1972; Telang et al., 1991; Gordeev and Sidorov, 1993, among others). Because of the size of these rivers, however, estimates of their fluxes to the marine environment integrate the results of weathering over large watersheds that include a variety of morphoclimatic zones (i.e., tundra, taiga and temperate). While these studies provide for a general understanding of such things as denudation rates and fluxes from large high latitude watersheds, the scaling up of such rates to estimate the total contribution of arctic and subarctic regions to global inputs to the ocean may be questionable, since much of the discharge from this region is delivered by small rivers.

Most estimates of global river fluxes of materials to the oceans are based on results of studies of the largest rivers of the world and therefore, account for no more than about one-third of the total freshwater discharge (see Holland, 1978). For example, Spitzzy and Leenheer (1991), using SCOPE carbon data for twenty of the largest rivers in the world (representing 37.7% of the global discharge), extrapolated the dissolved organic carbon flux estimated for them to global discharge to obtain a value of  $218 \times 10^{12} \text{gC/y}$ . Similarly typological approaches by Meybeck (1988) and Schlesinger and Melack (1981) weighed typical values of DOC concentrations in watersheds of different morphoclimatic types to their respective contribution to global runoff to make global dissolved organic carbon flux estimates.

But small rivers deliver materials to the oceans differently than large ones. And smaller river systems, which are more representative of the global land-sea boundary, clearly provide the greater amount of freshwater discharge to the oceans. Because they have smaller watersheds, residence times of weathered material or fixed carbon are likely to be shorter in small river systems than in larger river systems which have extensive and more efficient storage systems (i.e., floodplains, reservoirs, etc.). It is thus likely that delivery of materials, such as dissolved organic carbon, per unit area from small watersheds may be quite different than that from larger watersheds, even when morphoclimatic characteristics of the watersheds are

similar. Milliman and Syvitski (1992) clearly demonstrate this for the yield (mass/km<sup>2</sup>/yr) of suspended solids to the oceans. Their results show a strong inverse relationship between watershed size and sediment yield.

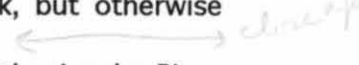
Thus, given that rivers of small watersheds clearly discharge more suspended solids per drainage basin size than do larger ones, scaling up data, from representative rivers, to global sediment discharge must take into account the relative importance of contributions of the different size classes of rivers. Similar arguments can be made for scaling up other riverine fluxes to the oceans. In addition, not only must data from smaller rivers be represented in global mass balances, but representation must also include results from smaller river systems representing different morphoclimatic zones.

### Research Program

We carried out one of two planned sampling campaigns in the Anadyr river-estuarine system during late August of this year (1994) to collect dissolved and particulate samples from various sub-basins to assess concentrations of radionuclides and to evaluate the results of weathering in this taiga-tundra morphoclimatic watershed. The second campaign will be to collect samples from the Anadyr estuary to assess fates and fluxes of organic carbon, nutrients and trace elements in and through this system.

The Anadyr River is the major river draining the Chuckotka Peninsula and discharges directly into the Bering Sea. The drainage basin is 191,000 km<sup>2</sup> and straddles the Arctic Circle. The watershed is dominated by a tundra biome but some sub-basins are dominated by taiga (Shumilin, pers. comm.). The river is frozen all but a few months of the year (i.e., June-September) when it transports its approximately 50 km<sup>3</sup> annual discharge. The dissolved load of the river has been estimated at ca.  $1.8 \times 10^6$  tons per year, whereas its suspended load is relatively small; although this is based on few data (Shumilin, pers. comm.).

We have been funded, at a modest level (i.e., \$90 K), by the Office of Naval Research, as a part of its initiative of radioactive contamination of the arctic environment, to collect bottom and suspended sediments from the Anadyr River for radionuclide analysis. This work was to be carried out in cooperation with colleagues at the Pacific Oceanological Institute (POI) of the Far Eastern Branch of the Russian Academy of Sciences, but we were generally left to our own devices for our first campaign.

The funds provided by ONR provide for travel and much of the field logistics costs in the watershed. The NSF component of this research provided additional funds for extended field sampling into the estuary of the Anadyr and for additional analytical work, but otherwise benefits from the coordination and logistics established through the ONR grant. 

For the NSF portion of this project, samples collected from the tributaries of the Anadyr River will be analyzed for major ion, nutrient and trace elements. This will provide data for the more important sub-basins of the Anadyr. Variability of solute and sediment concentrations from different sub-basins will allow for better estimates of flux and denudation rate. Although more sampling campaigns would be desirable the planned sampling should provide an understanding of the greatest variability.

A transect of samples through the estuary of the Anadyr will be collected during our next

campaign to assess estuarine processes that affect transport and fate of trace elements and carbon through the system. The low particle concentration and the expected high DOC concentration, common to northern latitude rivers (Spitzzy and Leenheer, 1991), provide unique estuarine characteristics for which only a few results of studies of such systems exist in the literature (e.g., Martin et al., 1991).

The results of these studies will be compared to those of Gordeev and Sidorov (1993) and Martin et al. (1993) on the Lena. The Lena is somewhat similar morphoclimatologically to the Anadyr but has a drainage basin that is ten times larger. Thus, comparisons of weathering chemistry and chemical fluxes between the two systems will provide insight into the significance of watershed size on material mobilization and transport for arctic-subarctic rivers. For example, Gordeev and Sidorov (1993) calculate a chemical denudation rate of about 20 t/km<sup>2</sup>/yr for the Lena Watershed. Using the data provided above this rate for the Anadyr is less than 10 t/km<sup>2</sup>/yr, implying that the mostly tundra watershed of the Anadyr weathers more slowly; a not so surprising conclusion.



## APPENDIX I

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